

# **JUVENILE HEMOCHROMATOSIS GENE (HFE2A), EXPRESSION PRODUCTS AND USES THEREOF**

1. This patent application claims priority of US provisional applications Serial No. 60/462,867, filed 15 April 2003, Serial No. US/60/488,607, filed 18 July 2003, and Serial No. 60/498,458, filed 28 August 2003, the disclosures of which are hereby incorporated by reference in their entirety.

## **FIELD OF THE INVENTION**

The present invention relates generally to the field of iron metabolism diseases, especially juvenile hemochromatosis, to a gene associated therewith, and to methods of using this gene, including expression products thereof, for the screening and identification of agents useful in the treatment of diseases of iron metabolism, including methods of such treatment.

## **BACKGROUND OF THE INVENTION**

At least 4 iron-overload disorders labeled hemochromatosis have been identified on the basis of clinical, biochemical, and genetic characteristics. Hemochromatosis type 1 is classic hemochromatosis (sometimes designated "HFE") (see OMIM Number: 235200; Online Mendelian Inheritance in Man, OMIM™. Johns Hopkins University, Baltimore, MD, at [www.ncbi.nlm.nih.gov/omim/](http://www.ncbi.nlm.nih.gov/omim/)), an autosomal recessive disorder, which is caused by mutation in a gene designated HFE on chromosome 6p21.3. The medical disorder called juvenile hemochromatosis (sometimes called "JH" or "juvenile haemochromatosis"), is also known as hemochromatosis type 2 ("HFE2"). Hemochromatosis type 3 (HFE3; OMIM 604250), an autosomal

recessive disorder, is caused by mutation in the gene encoding transferrin receptor-2 (TFR2; OMIM 604720), which maps to 7q22. Hemochromatosis type 4 (HFE4; OMIM 606069), an autosomal dominant disorder, is caused by mutation in the SLC11A3 gene (OMIM 604653), which encodes ferroportin 5 and maps to 2q32.

In some families juvenile hemochromatosis shows linkage to chromosome 1q21, whereas in others it is caused by mutation in the gene encoding hepcidin antimicrobial peptide, which maps to chromosome 19q13. The two forms of juvenile hemochromatosis (HFE2) are tentatively designated 10 HFE2A and HFE2B, respectively. The present invention relates to the genetic basis of HFE2A, the form of JH linked to chromosome 1q21.

Juvenile hemochromatosis (JH) differs from typical hereditary hemochromatosis. While HFE has a prevalent male expression, JH affects both sexes equally. JH involves iron accumulation, which begins early in life 15 and typically causes clinical symptoms before the age of 30 years. JH is a more severe disease than typical hereditary hemochromatosis, with JH showing hypogonadotropic hypogonadism, heart failure, arrhythmias and/or cardiomyopathy as frequent features. If untreated, the disease is lethal because of cardiac and other complications.

20 Identification of 1q21 as the chromosomal location of HFE2A was first reported in Roetto et al., *Am. J. Hum. Genet.* 64:1388-1393 (1999) but this locus did not correspond to the chromosomal location of any known gene involved in iron metabolism.

The present invention provides identification of the hereditary basis for 25 HFE2A, thereby facilitating development of more potent agents for treating diseases of iron metabolism. Administration of the HFE2A gene or protein itself may be therapeutic. Alternatively, the underlying genetic mutation identifies a novel therapeutic target for treating diseases of iron metabolism. This therapeutic target can be used to identify and discover more effective 30 therapeutic agents. Diagnostic compounds, kits and methods using HFE2A are also included which may be used to diagnose JH as well as to diagnose

and predict onset and severity of adult hemochromatosis and to distinguish between types of iron metabolism disorders.

#### BRIEF SUMMARY OF THE INVENTION

5        The invention relates to the discovery that juvenile hemochromatosis (hemochromatosis type 2A, or HFE2A), is caused by a mutation in a human gene found at 1q22 having the nucleotide sequence as set out in SEQ ID Nos. 1 – 9, and/or the corresponding amino acid sequences as set out in SEQ ID Nos. 10-12. The gene and the protein are referred to herein as HFE2A and also as hemojuvelin, these words referring the gene, the gene product and the protein expressed therefrom, unless the context specifies otherwise. The gene has also been named HFE2, by which is meant the form JH caused by the gene at 1q21. This naming protocol is not essential to the invention claimed herein.

10      15      In one aspect, the present invention relates to a method for identifying an agent that modulates hemojuvelin, comprising contacting a test compound with hemojuvelin and determining a change in hemojuvelin activity due to the compound, thereby identifying a modulator of the type being sought. The modulator may be a drug-like small molecule, an antibody, an antisense nucleic acid, a ribozyme or any other compound which changes the activity of the gene or protein.

20      25      In one aspect, the present invention relates to method for identifying an agent that modulates HFE2A gene expression, comprising contacting a test compound with a polynucleotide comprising a HFE2A gene and under conditions promoting expression of said gene (i.e., conditions wherein the polynucleotide is being expressed) and determining a change in expression due to the presence of the test compound. This identifies the test compound as such a modulator. In a preferred embodiment, this change in expression is detected as a change in transcription of the gene, preferably where the gene is a mammalian gene and most preferably where the gene is expressed by a cell.

In another aspect, the present invention relates to a method for identifying an agent that modulates HFE2A gene expression, comprising contacting a test compound with a reporter gene operably linked to a promoter sequence and determining a change in expression of the reporter gene due to the test compound, thus identifying a modulator of the construct. Preferably, this is modulation of transcription of said reporter gene operably linked to an HFE2A promoter, most preferably a mammalian HFE2A, such as a mouse, rat or human HFE2A promoter.

In a further aspect, the present invention relates to a method for 10 treating and/or preventing a disorder in an animal comprising administering to an animal afflicted therewith, or at risk of developing said disorder, a therapeutically effective amount of an HFE2A modulator. In a preferred embodiment, the HFE2A modulator exhibits modulating activity in a method of the invention, most preferably wherein said agent was first identified as an 15 HFE2A modulator using said method and was not otherwise known to have such activity.

In a yet further aspect, the present invention relates to a method to 20 diagnose individuals afflicted with or at risk of developing HFE2A or a related disorder comprising determining the nucleic acid sequence of the HFE2A gene in said individual wherein a mutation or polymorphism of said gene identifies said individual as an individual afflicted with or at risk of developing HFE2A or a related disorder.

The present invention also contemplates a method for identifying a 25 compound capable of modulating a HFE2A activity, comprising: (a) contacting a cell which expresses HFE2A with a test compound; and (b) assaying the ability of the test compound to modulate the transcription of a HFE2A nucleic acid or the activity of HFE2A polypeptide, thereby identifying a compound capable of modulating a HFE2A activity. In a preferred embodiment of such method, the compound is an anti-HFE2A polypeptide antibody, a ribozyme or 30 is an antisense HFE2A nucleic acid molecule. In one preferred embodiment thereof, the compound is a HFE2A ribozyme.

The present invention also encompasses an isolated polynucleotide or isolated polypeptide of the genes disclosed herein.

#### BRIEF DESCRIPTION OF THE DRAWINGS

5 Figure 1 is a schematic of LOC148738 Gene structure. The LOC148738 Gene has four exons and five transcripts. The five transcripts code for 3 proteins of 200 AA, 313 AA and 426 AA. Exon 2 was predicted by Ensembl from cDNA sequence AK098165.1. The acceptor site for Exon 2 is inferred from the genomic sequence. Exons 3a and 3b have the same  
10 acceptor site but different donor sites. Untranslated sequence is white, translated sequence is black. The transcripts are listed from longest to shortest.

Figure 2 is an alignment of the human, mouse and rat promoter sequences for HFE2A. The transcriptional start site of the human sequence begins at position 1514 of this alignment and exon 1 ends at position 1676.  
15 Three repetitive sequences are present within the human sequence, a (TAGA)n at position 58 to 129, an alu repetitive element at position 324 to 603 and a (GGAA)n at position 604 to 702. These sequences are not present in the rodent sequences and possibly define the promoter boundary for the  
20 gene. Sequence homology between species is lost 5' of position 844 of this alignment, about 670 bp 5' of the transcriptional start. A putative transcriptional initiation site (TATA) is conserved in all three species, at 27 to 24 bp 5' of the transcriptional start in the human.

Figure 3 shows a Protein Sequence Alignment of Human LOC148738  
25 426 aa Gene Product (Protein3) and human paralogs; Human Repulsive Guidance Molecule (Human RGM) (NCBI: NP\_064596.1) on Chromosome 15 and ENSESTP00000023393 (Ensembl) identified on Chromosome 5.— Comparison of human paralogs

Figure 4 shows a Sequence Alignment of LOC148738 sequences  
30 using clustalx. Human (Protein3), Mouse (Ensembl: ENSMUSESTP00000016634), Rat (Translated from NCBI: AK098165.1) Though annotated as human sequence it is 99.9% identical to Rat genomic

sequence and only 86.6% identical to human genomic sequence) and Fugu (Ensembl: SINFRUP00000138308).

Figure 5 shows a Protein Sequence Alignment of Human LOC148738 gene product and Chicken Repulsive Guidance Molecule (RGM). Human 5 (Protein3), Chicken\_RGM (Translation of NCBI: AY128507.1). A = Signal Peptide, B = RGD, C = N-Glycosylation site, D = Partial von Willebrand Type D Domain, E = GPI modification , Arrow = Possible cleavage site.

Figure 6A shows a summary of high degree of similarity between homologs of several species.

10 Figure 6B shows the high degree of similarity between genes similar to HFE2A in different species.

Fig 7(a) – Structural features in the 426 aa translated open reading frame of LOC148738. RGD – cell attachment tri amino acid motif, vWF – Partial von Willebrand factor type D domain and TM – Transmembrane 15 domain. The arrows mark a possible proteolytic site between positions 172 and 173, a furin cleavage site between positions 335 and 336 and a predicted GPI modification site at position 400. Fig. 7(b) shows the prediction of signal peptide cleavage site in 426 aa translation of HFE2A using SignalP (Henrik Nielsen et al. *Protein Engineering*, 10, 1-6 (1997)). Peptide cleavage site is 20 predicted to be between S35 and Q36. Figure 7(c) shows the prediction of transmembrane regions in 426 aa translation of HFE2A using TMHMM. The transmembrane region is from residues 403-425. Figure 7(d) shows the identification of partial von Willebrand Type D domain (57%) using NCBI Conserved Domain Search. (LOC148738 = HFE2A); Figure 7(e) shows 25 Possible proteolytic cleavage site (arrow) between residues 172D and 173P identified by sequence comparison with Chicken Repulsive Guidance Molecule (RGM).

Figure 8 shows Nucleic acid and amino-acid sequence of 426 aa open-reading frame translated from Transcript4 of LOC148738 (Protein3). This 30 protein is identical to the Ensembl protein ENSP00000304614 from the predicted Ensembl transcript ENST00000306561. **Box**, initiating codon; **triangle**, potential signal peptide cleavage site; **dots**, RGD site; **cross**,

predicted O-glycosylation sites (NetOGlyc2.0 predicted); diamonds, predicted N-glycosylation sites (NetNGlyc 1.0 predicted); arrow, putative cleavage site from comparison with chicken RGM; double arrow, furin cleavage site; square, predicted GPI anchor modification site; asterix, stop codon.

5 Fig 9 (a) – (e) – shows family pedigrees used to identify genetic mutation causing juvenile hemochromatosis.

#### DETAILED DESCRIPTION OF THE INVENTION

10 The present invention provides a gene and its corresponding protein related to diseases of iron metabolism, referred to as hemojuvelin or HFE2A. Hemojuvelin and HFE2A refers to both the gene, the gene product and the protein expressed therefrom, unless the context specifies otherwise.

15 In accordance with the present invention, the human HFE2A gene is disclosed. This gene, when mutated, results in juvenile hemochromatosis (hemochromatosis type 2A). The gene has also been named HFE2, by which is meant the form JH caused by the gene at 1q21. The gene product/protein is also sometimes called "hemojuvelin." This naming protocol is not essential to the invention claimed herein.

20 In one aspect, the invention relates to the nucleic acid sequence for HFE2A, including the genomic sequence, mRNA or cDNA, polymorphic, allelic, isoforms (adult, neo-natal, etc.) and mutant forms thereof, and nucleic acid constructs of the gene, including vectors, plasmids and recombinant cells and transgenic organisms containing or corresponding to HFE2A (or knock-outs thereof). Such nucleic acid sequences are set forth in SEQ. ID NOS. 1 – 25 9, and 13 - 22.

20 In another aspect, the invention relates to the gene product of HFE2A, sometimes called herein hemojuvelin or HFE2A polypeptide, including the polypeptide, protein, and amino acid sequence, and the polymorphic, allelic, isoforms (adult, neo-natal, etc.) and mutant forms thereof, mRNA or other transcripts of HFE2A, and recombinant cells and transgenic organisms wherein this polypeptide or a polypeptide corresponding thereto is expressed.

Such amino acid sequences are set forth in SEQ. ID NOs: 10 - 12 and 23 - 28.

In one aspect of the present invention, HFE2A is incorporated into a screening assay whereby compounds (potential therapeutic agents) are 5 tested to determine if they modulate HFE2A gene expression activity, thereby identifying potential therapeutic agents.

In accordance with the foregoing, the present invention relates to a method for identifying an agent that modulates HFE2A gene expression, comprising:

10 a) contacting a test compound with a cell expressing an HFE2A gene;  
b) determining a change in expression of said HFE2A gene as a result of said contacting,

wherein a change in expression identifies said test compound as an agent that modulates HFE2A gene expression.

15 In a preferred embodiment, this change in expression is detected by detecting a change in transcription of said gene, such as where there is a decrease or increase in transcription. In another preferred embodiment, the HFE2A gene is a mammalian HFE2A gene, most preferably where the mammal is a mouse, rat or human.

20 In another preferred embodiment, the gene whose modulation is to be determined is present in a mammalian cell, preferably a recombinant cell, including where the cell is a macrophage, inflammatory cell, liver cell, hepatocyte, intestinal cell, hematopoietic cell, pancreatic cell, skeletal muscle cell or a cell of the nervous system.

25 In another aspect, the present invention relates to a method for identifying an agent that modulates the activity of an HFE2A polypeptide, comprising:

a) contacting a test compound with an HFE2A polypeptide and under conditions supporting an activity of said polypeptide; and

30 b) determining a change in said activity of said polypeptide as a result of said contacting,

wherein a change in the activity identifies said test compound as an agent that modulates the activity of an HFE2A polypeptide.

In preferred embodiments of such methods, the HFE2A-encoded polypeptide is a mammalian HFE2A polypeptide, most preferably from mouse, 5 rat or human.

In other preferred embodiments, the modulation is a decrease or increase in said biological activity. In a highly useful embodiment, the polypeptide is in, or is part of, a cell, preferably a mammalian cell, most preferably a recombinant cell, including where the cell is a macrophage, 10 inflammatory cell, liver cell, hepatocyte, intestinal cell, hematopoietic cell, pancreatic cell, skeletal muscle cell or a cell of the nervous system. In other preferred embodiments, the cell has been engineered to contain said polypeptide, such as by genetic engineering, especially where said cell does not express said polypeptide absent said engineering.

15 In an additional preferred embodiment, the polypeptide is encoded by a polynucleotide having the sequence selected from the group consisting of SEQ ID NO: 1, 2, 3, 4, 5, 6, 7, 8 and 9, most preferably wherein said polypeptide comprises an amino acid sequence selected from the sequence of SEQ ID NO: 10, 11 and 12.

20 The present invention also relates to a cell line comprising a one or more of said polynucleotides of SEQ ID NO: 1, 2, 3, 4, 5, 6, 7, 8 and 9, including recombinant forms of the polynucleotides, as well as a cell line comprising one or more of the polypeptides of SEQ ID NO: 10, 11 and 12, preferably a recombinant form of the polypeptide. In another embodiment, the 25 present invention relates to use of such a cell line in a method for identifying compositions which modulate expression or activity of hemojuvelin.

In a further aspect, the present invention relates to a method for treating and/or preventing a disorder in an animal comprising administering to an animal afflicted therewith, or at risk of developing said disorder, a 30 therapeutically effective amount of an HFE2A modulator. In a preferred embodiment, the HFE2A modulator exhibits modulating activity in a method of the invention, most preferably wherein said agent was first identified as an

HFE2A modulator using said method and was not otherwise known to have such activity. In a preferred embodiment of such method, the HFE2A modulator is a selective HFE2A agonist, or a selective HFE2A antagonist, including pharmaceutically acceptable salts thereof, and/or any combinations 5 of these, including where these are in a pharmaceutically acceptable carrier. In an embodiment, said disorder is a disease of iron metabolism, including an iron overload disorder and/or an iron deficiency disorder. Such disease of iron metabolism may also include one or more of Type I diabetes, Type II diabetes and insulin resistance.

10        In a yet further aspect, the present invention relates to a method to diagnose individuals afflicted with or at risk of developing HFE2A or a related disorder comprising determining all or part of the nucleic acid sequence of the HFE2A gene in said individual wherein a mutation or polymorphism of said gene identifies said individual as an individual afflicted with or at risk of 15 developing HFE2A or a related disorder. In another such embodiment, the present invention relates to a method to diagnose individuals affected by or at risk of developing HFE2A or a related disorder comprising determining all or part of the amino acid sequence of HFE2A polypeptide in said individual wherein a mutation or polymorphism of said gene identifies said individual as 20 an individual affected by or at risk of developing HFE2A or a related disorder.

      The present invention also contemplates a method for identifying a compound capable of modulating a HFE2A activity, comprising: (a) contacting a cell which expresses HFE2A with a test compound; and (b) assaying the ability of the test compound to modulate the transcription of a HFE2A nucleic 25 acid or the activity of HFE2A Polypeptide, thereby identifying a compound capable of modulating a HFE2A activity. In a preferred embodiment of such method, the compound is an anti-HFE2A polypeptide antibody, a ribozyme or is an antisense HFE2A nucleic acid molecule. In one preferred embodiment thereof, the compound is a HFE2A ribozyme. In another embodiment, the 30 compound is a small organic molecule.

The present invention also encompasses an isolated polynucleotide comprising a polynucleotide having a nucleotide sequence with at least 60 percent identity to a sequence selected from the group consisting of SEQ ID NO: 1, 2, 3, 4, 5, 6, 7, 8, 9, 19, 20, 21 and 22. In other embodiments thereof, 5 said percent identity is at least 70 percent, more preferably at least 78 percent, even more preferably at least 90 percent, yet more preferably at least 95 percent, still more preferably at least 98 percent, and most preferably where the nucleotide sequence is a member selected from the group consisting of SEQ ID NO: 1, 2, 3, 4, 5, 6, 7, 8, 9, 19, 20, 21 and 22.

10 In another such embodiment, the present invention specifically encompasses an isolated polypeptide comprising a polypeptide having an amino acid sequence with at least 90 percent identity to an amino acid sequence selected from the group consisting of SEQ ID NO: 10, 11, 12, 23, 24, 25, 26, 27 and 28, preferably at least 95 percent, more preferably at least 15 98 percent and most preferably where the amino acid sequence is selected from the group consisting of SEQ ID NO: 10, 11, 12, 23, 24, 25, 26, 27 and 28.

20 The present invention also encompasses embodiments where the agents identified by the methods of the invention, or useful in the methods of the invention, may be present in the form of a composition for treating a disease of iron metabolism comprising a therapeutically effective amount of a 25 polypeptide of the invention, or a pharmaceutically active fragment thereof, in a pharmaceutically acceptable carrier. In accordance therewith, the present invention specifically contemplates a method for treating a disease of iron metabolism comprising administering to a patient in need thereof a therapeutically effective amount of such a composition. In an embodiment thereof, the disease is juvenile hemochromatosis.

30 In a further aspect, the present invention relates to a method for identifying an agent for the treatment of a disease of iron metabolism, comprising:

a) administering to an animal an agent found to have activity using a method as disclosed herein, and

b) detecting in said animal a change which is indicative of a change in iron metabolism due to said administering,

thereby identifying an agent for the treatment a disease of iron metabolism.

5 Preferably, the animal is a mammal, such as a human being. In specific embodiments, the change in iron metabolism may be a change in storage tissue distribution of iron.

10 In a preferred embodiment of the invention, the compound identified which modulates HFE2A is selective for HFE2A ahead of related genes or proteins, and therefore does not significantly modulate the activity of such other related genes or proteins by direct interaction.

15 In a further aspect, the present invention relates to a method for treating a condition in an animal afflicted with a disease of iron metabolism comprising administering to said animal an effective amount of an agent first identified by an assay method of the invention. Preferably, said animal is a human patient, such as a patient afflicted with a chronic disease of iron metabolism.

20 In a further aspect, the compounds identified by the assays disclosed herein, and the methods of treating patients with such compounds, are applied to alternative or additional indications beyond diseases of iron metabolism, which are found to be treatable by modulating HFE2A activity.

25 In a further aspect, the present invention relates to compounds that modulate HFE2A that may now be identified by those skilled in the art. These compounds include antibodies, antisense compounds, gene therapy vectors and proteins, and small molecule organic compounds.. The invention also comprises the use of these compounds for treatment of diseases associated with aberrant HFE2A activity. In one embodiment, the use of the compounds for treatment of disease of iron metabolism.

30 In another aspect, the present invention relates to a method for producing a product comprising identifying an agent according to the process of the invention wherein said product is the data collected with respect to said agent as a result of said process and wherein said data is sufficient to convey the chemical structure and/or properties of said agent.

In another aspect, the present invention relates to diagnostic and pharmacogenomic compositions, kits and methods which identify the presence or absence in a patient of one or more mutations in a polynucleotide 5 or a polypeptide corresponding to SEQ ID NOs: 1-12, including those specific mutations identified at SEQ ID NOs 14, 16, and 18, and other mutations that may be subsequently discovered to be relevant. This embodiment is useful in diagnosing the presence or absence of juvenile hemochromatosis. It is also useful for diagnosis of adultonset hemochromatosis, and for the prediction of 10 onset and severity thereof.

Figure 1 illustrates alternative splice variants that are generated during transcription of the HFE2A gene. For convenience, the nucleotide sequences of the coding exons are set out as follows:

SEQ ID NO.	Description
1	Sequence of Exon 1
2	Sequence of Exon 2
3	Sequence of Exon 3a
4	Sequence of Exon 3b
5	Sequence of Exon 4

15

The alternative splice variants generated from the gene produce at least 5 transcripts. The nucleotide sequence of each of transcripts 1 to 4, corresponding to a cDNA sequence (or a processed mRNA sequence if T is converted to U) is set out as follows:

20

SEQ ID NO.	Description
6	Wild-Type Human HFE2A putative cDNA - Transcript 1 (exon 1, 4)
7	Wild-Type Human HFE2A putative cDNA - Transcript 2 (exon 1, 3a, 4)
8	Wild-Type Human HFE2A putative cDNA - Transcript 3 (exon 1, 3b, 4)
9	Wild-Type Human HFE2A putative cDNA - Transcript 4 (exon 1, 2, 3b, 4)

Each of these four transcripts of the HFE2A gene may be translated into an HFE2A polypeptide. Transcripts 1 and 2 generate the same full length proteins, hence there are 3 full-length proteins of 200 amino acids (a.a.), 313 a.a. and 426 a.a., respectively. The amino acid sequence generated from 5 each transcript is set out as follows:

SEQ ID NO.	Description
10	Wild-Type Human HFE2A Polypeptide – Protein 1 (Transcripts 1 & 2)
11	Wild-Type Human HFE2A Polypeptide – Protein 2 (Transcript 3)
12	Wild-Type Human HFE2A Polypeptide – Protein 3 (Transcript 4)

The longest cDNA sequence (Transcript 4, SEQ ID No. 9) and the longest protein sequence (Protein 3, SEQ ID No. 12) have been used as the basis for the sequencing numbering convention used in the instant 10 specification.

Aspects of the sequence of HFE2A have been previously published in various sources, including the following: Homo sapiens Official Gene Symbol and Name: LOC148738; NCBI LocusID: 148738; Other Names: ENSG00000168509 (Ensembl v. 12.31.1), NM\_145277 (RefSeq); Genomic 15 Location: 142000393 - 142004657 bp on chromosome 1 (Assembly: NCBI 31 assembly of the human genome, Freeze Date: November 2002) (Ensembl Version for reference sequences: Ensembl v. 12.31.1.) An incomplete fragment of HFE2A is contained in PCT publication WO 02/051438 where it was listed as RGM3 and implicated as a Repulsive Guidance Molecule in 20 neuronal development (3 amino acids, 9 nt missing from 5' coding end).

A positional cloning strategy, set out in Example 1 below, was used to confirm that chromosomal region 1q21 was highly associated with juvenile hemochromatosis. Candidate genes were investigated to determine if mutations were present. The HFE2A gene described herein was determined 25 to contain a variety of deleterious mutations as follows:

Table 1.

Mutation	Type	Sequence
c.296G>T, p.G99V	WT	acctgccgcgGggacctcgcc (SEQ ID NO: 31)
	MT	acctgccgcgTggacctcgcc (SEQ ID NO: 32)
c.842T>C, p.I281T	WT	gctgcctacaTtggcacaact (SEQ ID NO.13)
	MT	gctgcctacaCtggcacaact (SEQ ID NO.14)
c.959G>T, p.G320V	WT	tgtgtggggGgtgccctcca (SEQ ID NO.15)
	MT	tgtgtggggTgtgccctcca (SEQ ID NO.16)
c.1079delC, p.C361fsX366	WT	tactccattCctgtgtcttt (SEQ ID NO.17)
	MT	tactccatt_ctgtgtcttt (SEQ ID NO.18)
c.976C>T, p. R326X	WT	tccaagtcaGcactctctcg (SEQ ID NO. 29)
	MT	tccaagtcaGtactctctcg (SEQ ID NO. 30)

5 Table 1 shows genetic variations identified in HFE2A (ENSE00001277351). The cDNA position of the mutation is represented by the number in the first column (i.e.; c.665). The mutations are numbered starting from the initiating ATG codon in ENST00000306561 (transcript 4) (SEQ ID NO. 9). For each variation ten bases of sequence on either side is presented with the wildtype  
 10 (WT) and mutant (MT) base capitalized.

Table 2.

Variation	JH3	JH4	JH5	JH6	JH7	JH8	JH9	JH10	JH11	JH12
c.296G>T, p.G99V							TT			
c.842T>C, p.I281T		CC								
c.959G>T, p.G320V	TT		TT	TT	TT			TT	GT	TT
c.1079delC, p.C361fsX366						del/del				
c.976C>T, p. R326X									TC	

Table 2 shows genetic variations identified in Juvenile Hemochromatosis families. The first column describes the variation, the other columns present the genotype of each chromosome at the site of mutation of a proband in each family. JH3, 4, 5, 6, 7, 8, 9, 10 and 12 are homozygous for the variation.

5 JH11 is a compound heterozygote with two variations.

Segregation of the indicated mutations in HFE2A with affected HFE2A patients has now been confirmed in all affecteds in the families identified in Table 2. The variation is not found in 128 European and 37 Greek control (unaffected) individuals. Thus, the presence of 7 families having one coding 10 change resulting in a G320V, one family having a unique coding change resulting in a I281T, and two other families having a premature truncation of this protein is convincing evidence that mutations in HFE2A (Gene 3 (LOC148738) ENSG00000168509 v.12.31.1) cause Juvenile Hemochromatosis.

15 Another variation occurred in control samples (i.e. unrelated persons not affected with JH). Two of 128 Dutch controls are heterozygous for c.1207G>A, p.V403I. Since it was heterozygous in these two samples, no JH phenotype would be expected to be apparent, nor is it found in these individuals. This variation could be a single nucleotide polymorphism (SNP) 20 in the Dutch population which is not deleterious. Alternatively, it may be a potentially causal mutation of JH were it to appear in the homozygous form. At this point it is just a SNP, but it may be useful for diagnostic, or therapeutic purposes.

A significantly conserved genomic DNA promoter nucleic acid 25 sequence for HFE2A has been identified in humans, mouse and rat as follows:

SEQ ID NO.	Description
19	Promoter sequence – human
20	Promoter sequence – mouse
21	Promoter sequence – rat

Alignment of the promoter sequences in Figure 2 shows the high degree of conservation between species in the regulatory region. Sequence conservation is substantially lost about 670 nt 5' to the transcription initiation site in the human sequence.

5       Genomic sequence: the full human genomic sequence illustrating the nucleic acid sequence around HFE2A is set forth at SEQ ID NO. 22. Exons are indicated in capital letters.

In accordance therewith, a gene useful in the methods of the invention comprises a polynucleotide corresponding to a polynucleotide having a 10 nucleotide sequence selected from the group consisting of SEQ ID NO: 19, 20, 21 and 22.

In another aspect, the present invention relates to a method for identifying an agent that modulates HFE2A gene expression, comprising:

15       (a) contacting a test compound with a genetic construct comprising a reporter gene operably linked to an HFE2A promoter under conditions supporting expression of said reporter gene;

      (b) determining a change in expression of said reporter gene as a result of said contacting,

20       wherein a change expression identifies said test compound, or confirms said test compound, as an agent that modulates HFE2A gene expression.

25       In preferred embodiment thereof, the modulation is a decrease or increase in expression, especially transcription, of said reporter gene and includes embodiments where the HFE2A promoter is a mammalian HFE2A promoter, preferably a mouse, rat or human HFE2A promoter. In a highly preferred embodiment, the promoter has a nucleotide sequence of SEQ ID NO: 19.

30       In a preferred embodiment, the expression of said reporter gene is determined by measuring the activity of an enzyme, such as where the reporter gene encodes a protein having a readily measurable enzyme activity.

As used herein, the term "identifying" can include first identifying said test compound as an agent that modulates gene expression or a polypeptide activity (i.e., where the agent was not previously known or suspected of having this activity) or can include confirming such activity (where the agent 5 was already suspected of having this activity but was not clearly shown to have such activity) by performing one or more of the assays of the invention. For example, where an agent has previously been implicated in modulation of HFE2A gene or polypeptide activity, or where such agent was suspected, or otherwise believed to be, an agent capable of altering, modulating, or 10 affecting iron metabolism, such as where the agent has been implicated in regulating iron metabolism, and the activity of such agent is confirmed to have such activity utilizing a method of the invention, such agent is deemed to have been identified as having the indicated activity.

In another aspect, the present invention relates to a method for 15 identifying an agent that modulates HFE2A polypeptide activity, comprising;

- (a) contacting a chemical agent with said HFE2A polypeptide under conditions promoting protein:protein interactions, and/or
- (b) contacting a chemical agent with said HFE2A polypeptide under conditions promoting HFE2A ligand HFE2A receptor interactions, 20 and/or
- (c) contacting a chemical agent with said HFE2A polypeptide under conditions promoting modifications in lipid composition, and/or
- (d) contacting a chemical agent with said HFE2A polypeptide under conditions promoting alterations in associated second messenger 25 signaling

wherein such interaction, alteration or modification indicates modulation and thereby identifying the chemical agent as an agent that modulates HFE2A polypeptide activity.

30 HFE2A activity may be mediated through alteration of an associated second messenger.

In one highly useful embodiment, the genetic construct is in a cell, preferably a mammalian cell, most preferably a recombinant cell, such as where the mammalian cell is a macrophage, liver cell, hepatocyte, intestinal cell, inflammatory cell, liver cell, hepatocyte, intestinal cell, hematopoietic cell, 5 pancreatic cell, skeletal muscle cell or a nervous system cell.

Table 3 below sets forth other polymorphisms that have been identified in the HFE2A gene of control individuals (i.e. those with no clinical manifestation of Juvenile Hemochromatosis or other iron metabolism disorder). These polymorphisms, and others that may be discovered by those 10 skilled in the art, may be useful for diagnostic or therapeutic or other purposes.

TABLE 3

Mutation	Type	Sequence
c.1-15C>G, na	WT	gcctggaaaCctggctggat (SEQ ID NO: 33)
	MT	gcctggaaaGctggctggat (SEQ ID NO: 34)
c.98-6C>G, intronic 2-3	WT	tccctctgtCtttagctcat (SEQ ID NO: 35)
	MT	tccctctgtGtttagctcat (SEQ ID NO: 36)
c.205_206insAGG, p.G69_70insG	WT	gaggaggagg---ccggggtgga (SEQ ID NO: 37)
	MT	gaggaggaggAGGccggggtgga (SEQ ID NO: 38)
c.432C>G, p.A144A	WT	gcctccctgcCccggaccctt (SEQ ID NO: 39)
	MT	gcctccctgcGccggaccctt (SEQ ID NO: 40)
c.483C>A, p.P161P	WT	atggtcgtccCccggggttct (SEQ ID NO: 41)
	MT	atggtcgtccAccggggttct (SEQ ID NO: 42)
c.488G>C, p.G163A	WT	cgtcccccggGgttcttgcat (SEQ ID NO: 43)
	MT	cgtcccccggCgttcttgcat (SEQ ID NO: 44)
c.569C>A, p.A190D	WT	gtccaaggagCtggccctcta (SEQ ID NO: 45)
	MT	gtccaaggagAttggccctcta (SEQ ID NO: 46)
c.627G>T, p.A209A	WT	cccccatggcGttgggggcca (SEQ ID NO: 47)
	MT	cccccatggcTttgggggcca (SEQ ID NO: 48)
c.682C>A, p.Q228K	WT	taagaacatgCaggaatgcat (SEQ ID NO: 49)
	MT	taagaacatgAaggaatgcat (SEQ ID NO: 50)
c.929C>G, p.A310G	WT	gccttctcagCtgaacaggac (SEQ ID NO: 51)
	MT	gccttctcagGtgaacaggac (SEQ ID NO: 52)
c.1207G>A, p.V403I	WT	agatgctgggGttcctttc (SEQ ID NO: 53)
	MT	agatgctgggAttcctttc (SEQ ID NO: 54)

Capital letter indicates site and nature of polymorphism. WT = wild-type; MT = mutation.

Similarity to other Human genes

5 Figure 3 illustrates an alignment between HFE2A and 2 related proteins found in the human genome. The similarity suggests that some functionality may be shared or similar between these proteins.

Table 4 shows a comparison of Human LOC148738 426 aa protein sequence (Protein3) to Human Paralogs\* using BLAST\*\*

10 Table 4.

Paralog	Score	Alignment (a.a.)	Identity %	Positive %	Gaps %
Human RGM (SEQ ID No. 23)	370 bits (939)	432	48%	60%	12%
ENSESTP00000023393 (SEQ ID No. 24)	333 bits (844)	444	42%	55%	13%

\* ENSESTP00000023393 (Ensembl) on Chromosome 5 and Human Repulsive Guidance Molecule (Human RGM) (NCBI: NP\_064596.1) on 15 chromosome 15

\*\*Sequence comparison using "BLAST 2 Sequences" (Tatiana A. Tatusova, Thomas L. Madden (1999), FEMS Microbiol Lett. 174:247-250) Parameters: blastp, BLOSUM62 matrix, open gap penalty of 11, extension 20 gap penalty of 1, gap x\_dropoff of 50, word size of 3, expect 10

Conservation of HFE2A in other organisms.

2. Homologs of human HFE2A gene were found in mouse (Mus 25 musculus), rat (Rattus norvegicus) and fish (Takifugu rubripes ("Fugu")). Figure 4 sets out a sequence comparison at the nucleotide level of these sequences. The high degree of conservation of these sequence is shown in

Table 5, which shows a comparison of Human LOC148738 426 aa protein sequence (Protein3) to Orthologs\* using BLAST\*\*

5 Table 5.

SPECIES	Score	Alignment (a.a.)	Identity %	Positive %	Gaps %
Mouse SEQ ID No. 25	758 bits (1936)	420	88%	90%	0%
Rat SEQ ID No. 26	752 bits (1920)	426	86%	89%	0%
Fugu SEQ ID No. 27	336 bits (853)	383	46%	61%	4%

\* Organism sequences: Mouse (Ensembl: ENSMUSESTP00000016634), Rat (Translated from NCBI: AK098165.1) and Fugu (Ensembl: SINFRUP00000138308).

\*\*Sequence comparison using "BLAST 2 Sequences" (Tatiana A. Tatusova, Thomas L. Madden (1999), FEMS Microbiol Lett. 174:247-250) Parameters: blastp, BLOSUM62 matrix, open gap penalty of 11, extension gap penalty of 1, gap x\_dropoff of 50, word size of 3, expect 10

Comparison of human HFE2A with chicken RGM is shown in Figure 5. The 426 aa sequence translation of Human LOC148738 (Protein3 identical to ENSP00000304614) shares significant sequence homology with Chicken\_Repulsive Guidance Molecule (RGM) (Translation of NCBI: AY128507.1). Chicken RGM amino acid sequence is listed at SEQ ID No. 28. Using "BLAST 2 Sequences" (Tatiana A. Tatusova, Thomas L. Madden (1999), FEMS Microbiol Lett. 174:247-250) 395 of the residues align with 46% Identity, 61% Positives and 9% Gaps. The two proteins also share a N-terminal signal peptide, a RGD tri-amino acid motif that could be involved in cell attachment, a site identified as a possible cleavage site in Chicken RGM,

a partial (~57%) von Willebrand Type D domain, and a predicted N-Glycosylation site. Both proteins are also predicted to have GPI modifications at the C-terminus.

A visual overview of similarities shared between human HFE2A and 5 homologs in mouse, rat and fugu, as well as sequences from Macac RGM, Chicken RGM, Xenopus RGM and C.Elegans NP are shown in Figure 6. This degree of similarity illustrates that similar genes or proteins from other species may be useful for various embodiments of the invention. The protein also has 10 the sequence *Arg-Asn-Arg-Arg*<sup>335</sup> representing the consensus cleavage site (Arg-X-Lys/Arg-Arg) for the proprotein convertase furin (Molloy, S.S. et al. J. Biol. Chem., 267, 16396-16402, (1992)) which would result in cleavage between positions 335 and 336.

A comparison of sequences between related genes from human, mouse, rat, chicken and zebrafish is shown at Figure 6B. Orthologs of the 15 human HFE2A protein are found in mouse, rat and zebrafish (Fig. 6B). Sequence comparison shows that human HFE2A is >85% identical with the mammalian orthologs, and ~45% identical to the fish ortholog. The 426 amino acid translation of HFE2A also shares significant sequence similarity with the Repulsive Guidance Molecule (RGM or RGMA) of human (48% identity) and 20 chicken (46% identity) (Fig. 6B). In humans there is also a third RGM-like gene, RGMB, whose biological function is currently unknown.

### HFE2A Polypeptide Function

This invention teaches the important discovery that HFE2A is a critical 25 regulator of iron metabolism. Exactly how it is involved in this process remains to be fully clarified. Important information about the activity of this protein can be determined based on the analysis of protein domains.

The 426 aa LOC148738 gene product (Protein3) has structural features consistent with a GPI (Glycosylphosphatidylinositol) anchored protein 30 (Fig 7a) including a N terminal hydrophobic signal peptide for access to the Endoplasmic Reticulum, where GPI anchor addition occurs (residues 1-35 Fig. 7b) and a C terminal hydrophobic domain/GPI addition signal sequence

(residues 403-425 Fig. 7c) (Udenfriend S and Kodukula K Ann Rev Biochem 1995). The GPI predicting program big-Pi predictor predicts that this gene product is GPI modified, and that either amino acids 399 or 400 can act as the omega site (Eisenhaber et al., JMB, 292 (3), 741-758, 1999). Other features 5 identified are a RGD – cell attachment tri amino acid motif (residues 98-100) (Ruoslahti, E. Annu. Rev. Cell Dev. Biol. 12, 697-715 (1996)) and a partial von Willebrand factor type D domain. von Willebrand factor type D domains are required for multimerization of von Willebrand factor (residues 167-253) (Jorieux, S. et al., Blood 1998 Dec 15;92(12):4663-70). In addition, the protein 10 has a possible proteolytic cleavage site identified by sequence comparison with Chicken Repulsive Guidance Molecule (RGM) between residues 172 and 173 (Fig. 7e) (Monnier, P.P. et al. Nature 419, 392-394, 2002). Also present but not shown are N-glycosylation and O-glycosylation sites which appear to be consistent with consensus sequences.

15 Figure 8 shows a protein domain analysis of HFE2A from a nucleotide/amino acid perspective. Features of the sequence are illustrated therein.

20 Further aspects of HFE2A Polypeptide function at the biochemical level may be determined by those skilled in the art using standard techniques. It is clear from the instant invention that HFE2A Polypeptide is directly involved in 25 iron transport, as the absence of this gene in humans leads to the condition of juvenile hemochromatosis (type 2A) or HFE2A.

Sixteen human tissues were examined for *HFE2A* expression by probing Northern blots with a probe from exon 4. Significant *HFE2A* expression was detected in liver, heart (especially atria) and skeletal muscle 25 (data not shown).

Based on publicly available ESTs (expressed sequence tags), fragments of this gene has also been found to be expressed in the following tissues:

30 Human HFE2A: skeletal muscle, liver, sciatic nerve, Liver and Spleen, prostate, heart;

Mouse HFE2A: mammary gland, heart, tongue, liver, xiphoid cartilage  
,medulla oblongata

Rat HFE2A: brain, ovary, placenta, kidney, lung, liver, heart, muscle,  
spleen

5 Therefore the HFE2A gene appears to be widely expressed in many tissues, but at reasonably low levels.

While not wishing to be bound to any particular mechanism of action of how HFE2A mutation causes juvenile hemochromatosis, or leads to adult onset hemochromatosis, it is possible to speculate on different roles the 10 gene/protein of the invention may play in iron metabolism. For instance, the HFE2A protein may lie upstream or downstream of hepcidin in the iron metabolism pathway. One possibility is that the protein is the hepcidin receptor or a co-factor for the hepcidin receptor. Another possibility is that HFE2A functions in the transcription, translation and/or processing of 15 hepcidin, and is necessary for proper functioning of hepcidin. HFE2A may be a hepcidin interacting protein. An alternate function is that the HFE2A protein may be a secreted factor from the bone marrow or liver, acting in a paracrine fashion, as a hormone or hormone-like compound regulator of hepcidin levels.

These possible mechanisms of action are suggestive for further 20 exploration of the protein, but are not intended to be limiting on the scope of claims included below. In all of these scenarios, the functional consequences are the same, i.e. loss of function of HFE2A results in loss of the body's capacity to control iron metabolism through normal hepcidin function, thus precipitating the development of juvenile hemochromatosis, or adult onset hemochromatosis 25 (possibly where other factors in the hepcidin/HFE2A metabolic pathway are not fully functional). Thus, modulating the activity of HFE2A is a method to regulate serum levels, biodistribution, and/or metabolism of iron in the body.

Modulation of HFE2A is also a method for treating diseases which are not directly related to iron or iron metabolism. A function for HFE2A unrelated to 30 its proposed role in iron metabolism is that of regulating blood volume. HFE2A is highly expressed in heart, especially in the right atrium, and therefore it is possible that HFE2A plays a hematological role, such as in sensing circulating

blood volume and the regulation of blood volume. Alternatively, HFE2A may play a paracrine function in the heart protecting local myocytes from iron related disease. Compounds which modulate the activity of HFE2A are therefore useful in treating or preventing hematological disorders, cardiac disorders (including 5 but not limited to cardiac failure, cardiomyopathy, disorders of fluid imbalance, and arrhythmias), and hormonal disorders. Also important, because hepcidin levels are stimulated in bacterial infections, inflammation, response to LPS injection, etc, HFE2A is a suitable therapeutic target for mediating aspects of these disorders, and could be important in treatment of bacterial sepsis, etc.

10 This invention establishes that the function of HFE2A is an essential regulator of iron in the human body, regardless of its exact mechanism of action. It is therefore a desirable drug target for treating diseases of iron metabolism in animals. For example, because HFE2A is directly implicated in JH and adult onset hemochromatosis according to this invention, the inventors recognize that 15 JH and other diseases where iron metabolism is defective may be treatable by administering a chemical modulator of HFE2A. The disease may not necessarily be related to aberrant HFE2A gene or protein activity. For example, a compound which modulates HFE2A activity may compensate for insufficiencies in other aspects of the iron metabolism pathway. Or, a modulator of HFE2A may be 20 used to treat a disease which is indirectly responding to iron levels in the blood.

As used in this disclosure the phrase "disease of iron metabolism" is therefore to be construed in its broadest context. This includes diseases where aberrant iron metabolism directly causes the disease, or where iron blood levels are disregulated causing disease, or where iron disregulation is a consequence 25 of another disease, or where diseases can be treated by modulating iron levels, etc. More specifically, a disease of iron metabolism according to this disclosure includes iron overload disorders, iron deficiency disorders, disorders of iron biodistribution, other disorders of iron metabolism and other disorders potentially related to iron metabolism, etc. Even more specifically diseases of iron 30 metabolism includes hemochromatosis, ferroportin mutation hemochromatosis, transferrin receptor 2 mutation hemochromatosis, juvenile hemochromatosis, neonatal hemochromatosis, hepcidin deficiency, transfusional iron overload,

thalassemia, thalassemia intermedia, alpha thalassemia, sideroblastic anemia, porphyria, porphyria cutanea tarda, african iron overload, hyperferritinemia, ceruloplasmin deficiency, atransferrinemia, congenital dyserythropoietic anemia, anemia of chronic disease, anemia, hypochromic microcytic anemia, iron-  
5 deficiency anemia, conditions with hepcidin excess, Friedrieck's Ataxia, gracile syndrome, Hallervan Spatz disease, Wilson's disease, pulmonary hemosiderosis, hepatocellular carcinoma, cancer, hepatitis, cirrhosis of liver, pica, chronic renal failure, insulin resistance, diabetes, atherosclerosis, neurodegenerative disorders, multiple sclerosis, Parkinson's Disease,  
10 Huntington's Disease, Alzheimer's Disease.

In particular, a modulator of HFE2A can usefully treat anemia of chronic disease. Worldwide, anemia of chronic disease (ACD, also know as Inflammatory Anemia) is the second most common form of anemia. ACD represents the most common form of anemia in hospitalized patients. ACD is an  
15 acquired disorder seen in patients with a variety of conditions including infection, malignancy and chronic inflammation. It is characterized by retention of iron by macrophages and decreased intestinal iron absorption, which leads to reduced iron availability for erythropoiesis. Early in the course of their disease, patients with ACD have a mild, normocytic anemia due to impaired iron recycling. Later,  
20 due to the reduced intestinal absorption they become frankly iron deficient with a hypochromic microcytic picture. Initial studies examining the role of hepcidin in ACD show that excessive hepcidin production underlies ACD.

Loss-of-function of murine hepcidin leads to severe iron overload, mimicking the biochemical and clinical phenotype of JH. In contrast, in both  
25 animal models and human disease, hepcidin overexpression leads to macrophage iron retention and an iron deficient phenotype typical of the iron disturbances found in ACD. Existing therapy for ACD is mainly targeted to treating the underlying disorder, with no efficacious treatment specifically directed to amelioration of the iron phenotype. Therefore, therapeutic strategies  
30 to reduce hepcidin production, such as by inhibition of HFE2A represent an important novel approach to treating the iron disturbances seen in ACD.

In some cases the diseases and disorders included in the definition of "disease of iron metabolism" are not typically identified as being iron related. It is recognized by the instant invention that based on the tissue distribution of HFE2A (hemojuvelin) and its related protein, hepcidin, that iron metabolism may 5 play a significant role in these disease processes. For example, it has recently been shown that hepcidin is very highly expressed in the murine pancreas suggesting that diabetes (Type I or Type II), insulin resistance, glucose intolerance and other disorders may be ameliorated by treating underlying iron metabolism disorders: (See Ilyin, G. et al. 2003 Febs. Letters 542 22-26). As 10 such, these diseases are encompassed under the broad definition.

**Method of Treatment Using HFE2A as a Therapeutic Target.**

The discovery that mutations in HFE2A relate to clearly definable 15 physiological outcomes in humans (namely juvenile hemochromatosis), now allows the inventors to establish, for the first time, that hemojuvelin, the HFE2A Gene and HFE2A Polypeptide are useful as therapeutic targets in humans for the treatment of diseases of iron metabolism. The words "therapeutic target" are intended to mean that therapeutic intervention is achieved with therapeutic 20 agents that modulate the activity of the gene or protein. "Modulate" means to increase, to decrease, or to otherwise change the activity. Standard industrial processes are available to those skilled in the art to confirm the identity of the therapeutic agents which modulate the activity of the gene or protein, some of which are set out below.

25 In accordance with the foregoing, the present invention relates to a method for treating a disorder comprising administering to a person in need of such treatment an effective amount of a selective HFE2A agonist or antagonist, or a pharmaceutically acceptable salt thereof, or a pharmaceutical composition containing either entity.

30 In a preferred embodiment, said disorder is a disease of iron metabolism. In a further preferred embodiment, said administering is by oral or intravenous means.

Use of the HFE2A in Screening Assays for Identifying Therapeutic Agents and Classes of Potential Therapeutic Agents.

The present invention readily affords different means for identification of agents for treating diseases of iron metabolism according to their ability to 5 modulate the activity of HFE2A. Exemplary assay methods useful for the identification of such compounds are detailed herein, although those skilled in the art will be aware of alternative means.

In one series of embodiments described in some detail below, assay methods involve testing libraries of chemical compounds, either one at a time 10 or in combinations, in an assay format designed to measure a biological activity related to HFE2A. Those library compounds that modulate the biological activity in the desired fashion are thereby identified as therapeutic agents of the invention. In effect, a wide variety of compounds are sequentially tested against the assay to determine whether they influence a 15 measurable biological activity of the assay. Assays may be based one or more of the diverse measurable biological activities of a gene or polypeptide corresponding to HFE2A.

“HFE2A activity” or “HFE2A biological activity” as used herein, especially relating to screening assays, is to be interpreted broadly and 20 contemplates all directly or indirectly measurable and identifiable biological activities of the HFE2A gene, gene products and HFE2A Polypeptide. Relating to the purified HFE2A Polypeptide protein, HFE2A Polypeptide activity includes, but is not limited to, all those biological processes, interactions, binding behavior, binding-activity relationships, pKa, pD, enzyme 25 kinetics, stability, and functional assessments of the protein. Relating to HFE2A Polypeptide activity in cell fractions, reconstituted cell fractions or whole cells, these activities include, but are not limited the rate at which HFE2A Polypeptide performs any measurable biological characteristic and all measurable consequences of these effects, including cell growth, 30 development or behavior and other direct or indirect effects of HFE2A Polypeptide activity. Relating to HFE2A genes and transcription, HFE2A activity includes the rate, scale or scope of transcription of genomic DNA to generate RNA; the effect of regulatory proteins on such transcription, the

effect of modulators of such regulatory proteins on such transcription; plus the stability and behavior of mRNA transcripts, post-transcription processing, mRNA amounts and turnover, all measurements of expression and translation of the mRNA into polypeptide sequences, and all measurements of protein expression levels or dynamics. Relating to HFE2A activity in organisms, this includes but is not limited biological activities which are identified by their absence or deficiency in disease processes or disorders caused by aberrant HFE2A biological activity in those organisms. Some of the known or suggested biological activities are set out in the description of HFE2A provided in the specification, however those skilled in the art will be able to identify further measurable activities of HFE2A with routine techniques. Broadly speaking, HFE2A biological activity can be determined by all these and other means for analyzing biological properties of proteins and genes that are known in the art.

15 It is also recognized that those skilled in the art may prefer to use forms of HFE2A corresponding to the sequences disclosed herein, although not necessarily the same. For example, while screening assays preferably employ HFE2A from human, mouse, rat or fugu, other assays may utilize HFE2A from a different organism, preferably a vertebrate, and most preferably from a 20 mammalian species. Thus the invention encompasses the use of, including but not limited to, sheep, dog, cow or horse HFE2A, for the same purposes as set out more specifically herein for human HFE2A. The shared technical features of these forms of HFE2A, are that, when expressed, they have similar biological activity, and that they share functional similarity with HFE2A, 25 as the case may be, such as may be determined by those skilled in the art. The HFE2A gene and/or HFE2A Polypeptide according to the invention may also be obtained from other mammalian species, other vertebrates, invertebrates and microorganisms based on the disclosure herein.

30 Thus, the polynucleotides for use in the screening assays of the invention that "correspond to" the polynucleotide encoding HFE2A (processed or unprocessed, including naturally occurring splice variants and alleles) are at least 40%, preferably at least 50%, more preferably at least 60%,

especially at least 70%, even more preferably at least 80%, or even at least 85%, most preferably at least 90%, or even at least 95%, or most especially at least 98%, with the especially preferred embodiment of identical to, and especially having the sequence of, an RNA that would be encoded by, or be 5 complementary to, such as by hybridization under reasonably stringent conditions, with an HFE2A polynucleotide (SEQ ID NO: 1-9, or 13-22.). In addition, HFE2A protein sequences encoding the same polypeptides as any of the nucleic acid sequences corresponding to HFE2A, regardless of the percent identity of such sequences, are also specifically contemplated by any 10 of the methods of the present invention that rely on any or all of said sequences, regardless of how they are otherwise described or limited. Thus, any such sequences are available for use in carrying out any of the methods disclosed according to the invention. Such sequences also include any open reading frames, as defined herein, present within an HFE2A polynucleotide.

15 Because of the processing that may take place in transforming the initial RNA transcript into the final mRNA, the sequences disclosed herein may represent less than the full genomic sequence. They may also represent sequences derived from alternate splicing of exons. Consequently, the genes present in the cell (and representing the genomic sequences) and the 20 sequences disclosed herein, which are mostly cDNA sequences, may be identical or may be such that the cDNAs contain less than the full complement of exons found in the genomic sequence. Such genes and cDNA sequences are still considered corresponding sequences because they both encode similar RNA sequences. Thus, by way of non-limiting example only, a gene 25 that encodes an RNA transcript, which is then processed into a shorter mRNA, is deemed to encode both such RNAs and therefore encodes an RNA corresponding to an HFE2A sequence as disclosed herein. (Those skilled in the art understand that the word "encode" and its derivatives mean, in this field "can be transcribed into" or "can be translated into"). Thus, the 30 sequences disclosed herein correspond to genes contained in the cells and are used to determine relative levels of transcription because they represent the same sequences or are complementary to RNAs encoded by these

genes. Such genes also include different alleles and splice variants that may occur in the cells used in the processes of the invention.

As used herein, the term "percent identity" or "percent identical," when referring to a sequence, means that a sequence is compared to a claimed or 5 described sequence after alignment of the sequence to be compared (the "Compared Sequence") with the described or claimed sequence (the "Reference Sequence"). The Percent Identity is then determined according to the following formula:

$$\text{Percent Identity} = 100 [1-(C/R)]$$

10 wherein C is the number of differences between the Reference Sequence and the Compared Sequence over the length of alignment between the Reference Sequence and the Compared Sequence wherein (i) each base or amino acid in the Reference Sequence that does not have a corresponding aligned base or amino acid in the Compared Sequence and (ii) each gap in the Reference 15 Sequence and (iii) each aligned base or amino acid in the Reference Sequence that is different from an aligned base or amino acid in the Compared Sequence, constitutes a difference; and R is the number of bases or amino acids in the Reference Sequence over the length of the alignment with the Compared Sequence with any gap created in the Reference Sequence also being counted 20 as a base or amino acid.

If an alignment exists between the Compared Sequence and the Reference Sequence for which the percent identity as calculated above is about equal to or greater than a specified minimum Percent Identity then the Compared Sequence has the specified minimum percent identity to the 25 Reference Sequence even though alignments may exist in which the hereinabove calculated Percent Identity is less than the specified Percent Identity.

Where context indicates that sequences have been analyzed using the NCBI Blast tools, reports of sequence score, alignment, identity%, 30 postive% and gaps% have been generated based on these calculations: For the segment pair, the alignment score is the sum of the scoring matrix values. The theory of amino acid substitution matrices is described in [1], and applied to

DNA sequence comparison in [2]. The number of positives is the number of residues for which the alignment score has a positive value. Experimentation has shown that the BLOSUM-62 matrix [3] is among the best for detecting most weak protein similarities. [1] Altschul, S.F. (1991) "Amino acid substitution 5 matrices from an information theoretic perspective." *J. Mol. Biol.* 219:555-565. [2] States, D.J., Gish, W. & Altschul, S.F. (1991) "Improved sensitivity of nucleic acid database searches using application-specific scoring matrices." *Methods* 3:66-70. [3] Henikoff, S. & Henikoff, J.G. (1992) "Amino acid substitution matrices from protein blocks." *Proc. Natl. Acad. Sci. USA* 89:10915-10919.

10 As used herein, the terms "portion," "segment," and "fragment," when used in relation to polypeptides, refer to a continuous sequence of nucleotide residues, sequence forms a subset of a larger sequence. Such terms include the products produced by treatment of said polynucleotides with any of the common endonucleases, or any stretch of polynucleotides that could be 15 synthetically synthesized. These may include exonic and intronic sequences of the corresponding genes.

The instant invention provides numerous assays which measure an activity of HFE2A and are useful for the testing of compounds to identify which ones affect such activity. In terms of formatting the assays, the assays 20 may use whole cells, cell extracts or reconstituted cell extracts, or purified or semi-purified proteins, or they may be larger scale tissue or whole animal assays. Common assays use measurements based on fluorescence, luminescence, radioactivity, or other measures of protein or gene transcript levels, amounts, or stability. Polypeptide assays may also include those 25 wherein the HFE2A polypeptide is attached to a solid support, such as a resin or other polymer, especially where this is part of a column procedure for determining activity. Alternatively, batch procedures may also be used.

In one aspect, the present invention relates to a method for identifying an agent that modulates the activity of an HFE2A polypeptide, comprising:

30 a) contacting a test compound with an HFE2A polypeptide and under conditions supporting an activity of said polypeptide; and

b) determining a change in said activity of said HFE2A polypeptide as a result of said contacting,

wherein a change in the activity identifies said test compound as an agent that modulates the activity of an HFE2A polypeptide.

5 In a preferred embodiment, said gene has the sequence of SEQ ID NO: 1 - 9.

In a preferred embodiment, the observed change in activity in step (b) is a decrease or an increase in activity, most preferably wherein said change in activity is the result of binding to said polypeptide by said chemical agent of 10 step (b). In a preferred embodiment, such agents are useful for treating a disease of iron metabolism.

In other preferred embodiments, the polypeptide is part of an intact cell, preferably a mammalian cell, and which may be a recombinant cell. For HFE2A, cells of greatest interest include macrophages, hepatocytes, intestinal cells, 15 heart cells (especially atrial cells), pancreatic cell, skeletal muscle cell and cells of the bone marrow, although cells from other tissues may be employed. In one such embodiment, said cell has been engineered to comprise said polypeptide, including by genetic engineering, especially where the cell does not possess the polypeptide absent said engineering. Thus, the present invention specifically 20 contemplates embodiments in which the cell is engineered by other than genetic engineering, such as where the activity of a polypeptide is to be enhanced and the cell has been engineered to contain, or have on its surface, said polypeptide but wherein the polypeptide is present due to physical insertion of the polypeptide into the membrane or cytoplasm of the cell and not through 25 expression of a gene contained in the cell. Methods well known in the art, such as use of polyethylene glycol, viruses, and the like, are available to effect such insertions and the details of such procedures need not be further described herein.

In one preferred embodiment of such method, the polypeptide is a 30 polypeptide that reacts with an antibody that reacts with, or is specific for, a polypeptide having an amino acid sequence at least 95% identical to, more preferably at least 98% identical to, the sequence of SEQ ID NO: 10 - 12 and

where any difference in amino acid sequence is due only to conservative amino acid substitutions. In an especially preferred embodiment, the polypeptide has the amino acid sequence of SEQ ID NO: 10 - 12.

5        The HFE2A Polypeptide assays of the invention may employ compound screening technology such as (but not limited to) the ability of various dyes to change color, or fluorescent signaling/quenching in response to changes in assay conditions resulting from the activity of the polypeptides. Compound screening assays can also be based upon the ability of test

10      compounds to modulate the interaction of the target peptide (HFE2A Polypeptide) and known or discovered interacting proteins or protein receptors. Such interacting proteins can be identified by a variety of methods known in the art, including, for example, radioimmunoprecipitation, co-immunoprecipitation, use of epitope-tagged constructs in pull down

15      experiments, co-purification by extraction and chromatography techniques, and yeast two-hybrid screening. Such interactions can be further assayed by means including but not limited to direct detection methods such as surface plasmon resonance, fluorescence with fluorophores or fluorochromes and quenching with chromophores, radiolabelled proteins, fluorescence polarization, confocal fluorescence imaging or scintillation proximity

20      techniques. Indirect interactions may also be monitored through cell viability assays, second messenger reporting such as, G-protein coupled receptor assays, cAMP detection, nitric oxide synthase, phosphodiesterase activity, or lipid modification such as sphingomyelinase, inositol triphosphate assays.

25      Agents that have the effect of modulating the half-life of HFE2A Polypeptide are also useful for treating diseases of iron metabolism. By way of non-limiting example, an assay for this kind of agent comprises cells expressing a wild-type HFE2A Polypeptide wherein such polypeptides are transiently metabolically labeled during translation, contacted with a candidate

30      compound, and the half-life of the polypeptide is determined using standard techniques. Compounds that modulate the half-life of the polypeptide are useful compounds in the present invention.

In one such assay for which the polypeptides encoded by genes disclosed herein are useful, the purified or semi-purified HFE2A polypeptide (or a fragment thereof or an epitope-tagged form or fragment thereof) is 5 bound to a suitable support (e.g., nitrocellulose or an antibody or a metal agarose column in the case of, for example, a his-tagged form of said polypeptide). Binding to the support is preferably done under conditions that allow proteins associated with the polypeptide to remain associated with it. Such conditions may include use of buffers that minimize interference with 10 protein-protein interactions. If desired, other proteins (e.g., a cell lysate) are added, and allowed time to associate with the polypeptide. The immobilized polypeptide is then washed to remove proteins or other cell constituents that may be non-specifically associated with it the polypeptide or the support. The immobilized polypeptide can then be used for multiple purposes. In a 15 compound screening embodiment, such as that provided by Neogenesis Pharmaceuticals, Inc. (Cambridge, MA) the bound HFE2A Polypeptide will be employed in an automated ligand identification system, with low, medium or high-throughput capacity. In this case a pool of test compounds are exposed to HFE2A under conditions (i.e. buffers, temperatures, etc.) which promote 20 specific binding of the test compounds to the protein. Compounds with non-specific binding are separated from the mixture. HFE2A/ligand complexes are then collected, and bound ligands are released and measured by mass spectrometer. A data analysis system correlates mass data with the list of compound masses included in the original test compound mixture. In an 25 alternative embodiment, compounds can be tested for their ability to interfere with interactions between HFE2A Polypeptide and other bound molecules (which are presumably HFE2A Polypeptide interacting proteins). Compounds which can successfully displace interacting proteins are thereby identified as HFE2A Polypeptide modulating agents of the invention. Other well known 30 protein binding assays, which use purified or semi-purified target protein, can also be employed to identify test compounds with specific binding affinity for the protein.

In an alternative embodiment designed to identify HFE2A Polypeptide interacting proteins, the immobilized polypeptide is dissociated from its support, and proteins bound to it are released (for example, by heating), or, 5 alternatively, associated proteins are released from the polypeptide without releasing the latter polypeptide from the support. The released proteins and other cell constituents can be analyzed, for example, by SDS-PAGE gel electrophoresis, Western blotting and detection with specific antibodies, phospho-amino acid analysis, protease digestion, protein sequencing, or 10 isoelectric focusing. Normal and mutant forms of such polypeptide can be employed in these assays to gain additional information about which part of the polypeptide a given factor is binding to. In addition, when incompletely purified polypeptide is employed, comparison of the normal and mutant forms of the protein can be used to help distinguish true binding proteins. Such an 15 assay can be performed using a purified or semipurified protein or other molecule that is known to interact with a polypeptide encoded by an HFE2A polynucleotide.

This assay may include the following steps.

1. Harvest the encoded polypeptide and couple a suitable fluorescent 20 label to it;
2. Label an interacting protein (or other molecule) with a second, different fluorescent label. Use dyes that will produce different quenching patterns when they are in close proximity to each other versus when they are physically separate (i.e., dyes that quench each other when they are close 25 together but fluoresce when they are not in close proximity);
3. Expose the interacting molecule to the immobilized polypeptide in the presence or absence of a compound being tested for its ability to interfere with an interaction between the two; and
4. Collect fluorescent readout data.

An alternative assay for such protein interaction is the Fluorescent Resonance Energy Transfer (FRET) assay. This assay can be performed as follows.

1. Provide the encoded protein or a suitable polypeptide fragment thereof and couple a suitable FRET donor (e.g., nitro-benzoxadiazole (NBD)) to it;
- 5 2. Label an interacting protein (or other molecule) with a FRET acceptor (e.g., rhodamine);
3. Expose the acceptor-labeled interacting molecule to the donor-labeled polypeptide in the presence or absence of a compound being tested for its ability to interfere with an interaction between the two; and
- 10 4. Measure fluorescence resonance energy transfer.

Quenching and FRET assays are related. Either one can be applied in a given case, depending on which pair of fluorophores is used in the assay.

15 The description of the HFE2A provided herein teaches a wide variety of biological activities of HFE2A that may be useful for the development of low, medium or high-throughput screening assays.

20 One useful biological activity that works for a variety of assays is ligand binding (i.e. assays which either inhibit or enhance HFE2A binding with a ligand). The hepcidin protein (OMIM: 606464; See Roetto, A. et al. 2003. *Nature Genet.* 33: 21-22) may be a ligand of HFE2A. Those skilled in the art may find other ligands. Assays based on whole cells, cell extracts or purified proteins may be developed which measure the capacity of a test compound to inhibit or enhance HFE2A binding with a specific ligand.

25 Cell function assays can be designed. In these assays, a measurable cell function which is dependent on HFE2A activity can be measured to determine inhibition or enhancement by test compounds. Such functions include cell growth assays, such as where compounds are evaluated for their ability to influence axonal growth, in assays such as those described in PCT 30 patent publication WO 02/051438, incorporated herein by reference in its entirety. Based on the presence of RGD and von Willibrand factor-like domains, HFE2A may be involved in cell-cell adhesion. An assay can be

designed which relies on the biological activity of HFE2A induced adhesion, and measures a test compound's ability to modulate adhesion.

In other cell based assays, an HFE2A protein response is first calibrated. For example HFE2A may modulate release of iron by 5 macrophages to transferrin. Or, HFE2A may modulate transport of iron across a CaCo2 membrane. Alternatively, HFE2A may induce a change in NRAMP2 iron transport behavior in an assay. One may assay for compounds which modulate these induced responses to HFE2A and thereby find a modulator of a biological activity of HFE2A. Signaling assays can be developed based on 10 possible functions of HFE2A as a signaling molecule. Iron transport assays that may be adapted include iron uptake in an HFE-CHO cell model for duodenal crypt cells. This can be adapted to assay in 96-well plates wherein test compounds will reduce iron uptake. Similarly, test compounds may inhibit 59Fe-bound transferrin uptake in human hepatoma cells (HLF). Assays that 15 may be suitable for adaptation include those described in Su, M.A. et al. Blood, Vol. 92 No. 6 (September 15), 1998: pp. 2157-2163; Nunez MT, et al. J Nutr 1996 Sep;126(9):2151-8; Tandy S, et al. J Biol Chem 2000 Jan 14;275(2):1023-9; or Feeney GP and Worwood M. Biochim Biophys Acta 2001 Apr 23;1538(2-3):242-51). HFE2A shares sequence similarity and 20 similar structural domains with the human repulsive guidance molecule (RGM), (fig.3) and to chicken RGM-like molecule (fig5). RGMs are a family of proteins involved in neural development and immune response (see WO 02/051438), though assignment of at least some of these functions to HFE2A protein must be considered doubtful, as protein and mRNA expression is not 25 found in neural cells. In any case, related proteins are known to act locally on the cell membrane as receptors, initiating intracellular signals, and systemically as a cleaved soluble protein. Like the chicken RGM, HFE2A has a putative extracellular cleavage site suggesting that it acts as a soluble peptide. One proposed mechanism of action could be that this secreted 30 molecule interacts with proteins on the basal-lateral surface of the intestinal epithelial cells, like hepcidin, and modulates the apical surface uptake of iron from diet. This interaction could be direct, at the basal surface of the intestinal

cells, or via an upstream interaction resulting in modulating iron uptake. This direct or indirect effect can be assayed in a cell culture system.

An example of a compound screening assay which relies on an HFE2A induced response (i.e. an HFE2A biological activity) is a Caco2 HFE2A induced iron transport assay. Caco2 cells are a human colorectal carcinoma cell line and considered the standard for measuring intestinal absorption. These cells grown to confluence form distinct apical and basalatoral surfaces and tight junctions. Grown on permeable membranes in Transwell plate inserts, Caco2 cells become polarized with the basalatoral surface of the cell 5 on the membrane and exposed to the B chamber solutes, while the apical side of the cell is exposed to solutes in the A chamber. This system is useful to measure active transport of iron through the intestinal epithelium from A to B, mimicking transport from the intestinal lumen through the cell to the blood. A response to HFE2A can be induced by adding HFE2A to the B (baso- 10 lateral) chamber of the CaCo2 assay. Recombinant HFE2A can be produced in mammalian cells and the purified protein directly added to the B chamber. Alternatively, cultured cells can be transfected with HFE2A constructs and 15 then express HFE2A protein. Appropriate cells for transfection would be HepG2 or RAW cells, human liver carcinoma cells or mouse macrophage cells, respectively. These two cell types are known to be involved in iron 20 metabolism, and likely express HFE2A. The media from these transfected "donor" cells containing HFE2A can now be applied to the B chamber of the Caco2 cells, "acceptor" of the conditioned media, and iron absorption from the A chamber can be monitored. The transfected donor cells could also be 25 grown on the bottom of the B chamber surface, thus directly releasing HFE2A into the B chamber, within millimeters from the basal surface of the acceptor cells.

Whether HF2A acts as a receptor, intracellular signal molecule or secreted protein, this multicellular communication system can be applied to 30 measure an HFE2A induced response. The assay may measure iron transport, iron uptake from the A chamber, iron absorption and/or cell secretion of iron to the B chamber. This cell communication system can

thereafter be applied to primary drug compound screening for iron modulation in intestinal absorption.

Using whole cells or cell extracts, assays can be developed for compounds which increase or decrease GPI cleavage or secretion of HFE2A 5 or for compounds which increase or decrease N-glycosylation of HFE2A. Assays that measure compounds which modulate post-translational modifiers of HFE2A can be used to identify potential therapeutic agents.

Some assays preferably employ purified or semi-purified HFE2A protein assays. This protein may be the GPI-linked form, or the cleaved, 10 soluble form.  $I^{125}$  labelled HFE2A may be useful for these assays. Such assays include aggregation, assays which are designed based on the tendency of HFE2A to aggregate or homodimerize via the RGD or von Willibrand factor-like domains. In this assay, compounds are tested for their ability to enhance or prevent aggregation of homophilic dimerization domains. 15 In this case, the protein-protein interaction assays above can use two pools of HFE2A, each labelled with a different fluorophore. In some embodiments a GPI-cleaved form of HFE2A may be used with the GPI-linked form. An alternate semi-purified format includes yeast 2-hybrid and/or phage display formats, wherein HFE2A binding regions are incorporated into both bait and 20 prey vectors. This format would provide a moderately high throughput screening assay, suitable for radioimmunoassay or plate format..

In addition it is to be noted that HFE2A may interact with other known proteins of the iron metabolic pathway: Transferrin, Tf receptor, Hfe, hepcidin, p97 or other iron transporters, and receptors thereof. This interaction is a 25 useful activity which may be used as the basis for a screening assay.

Additionally, drug screening assays can also be based upon polypeptide functions deduced upon antisense interference with the gene function. Intracellular localization of HFE2A, or effects which occur upon a change in intracellular localization of such proteins, can also be used as an 30 assay for drug screening.

In accordance with the foregoing, the present invention provides the amino acid sequence of a protein, designated hemojuvelin or HFE2A, that is found in tissues of the human body (for example, SEQ ID NO: 10 - 12 from humans) and which is associated with hereditary transmission of juvenile hemochromatosis. In addition, several mutations, have been found in this sequence derived from individuals found to have juvenile hemochromatosis. Thus, agents that interact with hemojuvelin or HFE2A represent candidate compounds for evaluation as therapeutic agents of the invention.

Another broad category of screening assays is transcription assays.

10 These assays seek to identify compounds which modulate (i.e. increase or decrease) transcription of the HFE2A gene. Relating to transcription assays, in one aspect the present invention relates to a method for identifying an agent that modulates the activity of a polynucleotide whose transcription contributes to amelioration of a disease of iron metabolism, comprising:

15 a) contacting under physiological conditions a chemical agent with a polynucleotide corresponding to the promoter region of HFE2A (in a preferred embodiment, the promoter has the sequence of SEQ ID NO: 19); and

b) detecting a change in the transcription of said polynucleotide as a result of said contacting;

20 thereby identifying an agent that modulates transcription of said polynucleotide or gene activity.

Such modulation is preferably a decrease or an increase in transcription. In preferred embodiments, such transcription is measured by measuring the amount of a transcription product. In a convenient embodiment, the promoter 25 region of HFE2A is operably linked to a reporter gene, that is, a gene whose transcription is conveniently measured (for example, reporter genes such as Green Fluorescent Protein, luciferase, chloramphenicol acetyl-transferase (CAT), and the like).

In preferred embodiments, the polynucleotide whose transcription is to 30 be measured or monitored is present in an intact cell, preferably a mammalian cell, most preferably a cell selected from among macrophages, hepatocytes, intestinal cells, hematopoietic cells, pancreatic cell, skeletal muscle cell and

other cells of the bone marrow, neurological, CNS or spinal cells, although cells from other tissues may also be used. In additional preferred embodiments, such an intact cell is a cell that has been engineered to comprise said polynucleotide, such as by genetic engineering, preferably 5 wherein the cell does not express the subject gene or polynucleotide absent having been engineered to do so. Alternatively, non-recombinant cells can be employed, as for example, in cells of tissues or cell lines where the transcription of HFE2A is constitutive, or can be induced.

In accordance with the disclosure herein, upstream untranslated 10 regions and promoter regions of HFE2A Gene are readily obtained from SEQ ID No. 19 or 22 and other publicly retrievable sequence databases. Such genomic or untranslated regions may be included in plasmids comprising the identified gene, such as in assays to identify compounds which modulate transcription thereof. In one such assay, the upstream genomic region is 15 ligated to a reporter gene, and incorporated into a transcription plasmid. The plasmid is transfected into a cell, and the recombinant cell is exposed to test compound(s). Those compounds which increase or decrease the expression of the reporter gene are then modulators of the gene/protein, and are considered therapeutic agents of the invention.

20 The invention also claims recombinant cells engineered to express a polynucleotide or polypeptide as disclosed herein. The gene disclosed herein as being involved in HFE2A in an animal can be used, or a fragment thereof can be used, as a tool to express a protein, where such genes encode a protein, in an appropriate cell *in vitro*, or can be cloned into expression vectors 25 which can be used to produce large enough amounts of protein to use in *in vitro* assays for drug screening. Alternatively, the expression construct may employ the genomic promoter region of HFE2A and link it to a gene, such as a reporter gene, whose expression level is easily measured. Expression systems which may be employed include baculovirus, herpes virus, 30 adenovirus, adeno-associated virus, bacterial systems, and eucaryotic systems such as CHO cells. Naked DNA and DNA-liposome complexes can

also be used. The invention thus claims recombinant cell lines containing a heterologous HFE2A gene.

Such recombinant cells may be used in transcription assays for analyzing the levels of transcription of HFE2A Gene or a suitable reporter 5 gene after contacting said cells with agents that may have therapeutic properties. The levels of gene transcription can be quantified by Northern blot analysis or RT-PCR, or, alternatively, by measuring the amount of protein produced, by one of a number of methods known in the art, or by measuring the levels of biological activity of polypeptides encoded thereby or other 10 genes. In this way, the gene transcription can serve as a marker, indicative of the physiological response of the cells to the agent. Accordingly, this response state may be determined before, and at various points during, treatment of the individual with the agent.

Recombinant cell lines are also preferred for the preparation of purified 15 protein, if a purified protein assay is desired. Those skilled in the art are capable of producing recombinant cell lines and extracting protein fractions containing highly purified proteins. These samples can be used in a variety of binding assays to identify compounds which interact with the proteins. Compounds that interact are therapeutic agents of the invention, or analogs 20 thereof.

Target selectivity is an important aspect of the development of therapeutic agents. The present invention specifically contemplates the identification of chemical agents, especially small organic molecules, that agonize or antagonize the transcription of HFE2A Gene, as defined herein, or 25 the activity of the HFE2A Polypeptide (such as SEQ ID NO: 10 - 12 from humans) encoded thereby, with high specificity and that have little or no effect on other genes and/or polypeptides.

Thus, in one such preferred embodiment, the methods disclosed herein for identifying an agent that modulates, preferably inhibits, expression of a 30 gene corresponding to HFE2A, preferably having the sequence of SEQ ID NO: 1 - 9 from humans, or on the activity of a polypeptide encoded thereby, comprises first identifying such agent and then testing such agent for effects

on expression or activity of at least one other gene or polypeptide, preferably a gene or polypeptide with important physiological consequences that are preferably not disturbed by therapeutic intervention, and demonstrating little or no effect.

5        In another aspect, the invention provides a method for computationally identifying a compound of the invention. The method involves (a) determining the crystal structure of an active site of a HFE2A Polypeptide protein (i.e. through x-ray crystallography or other techniques); and (b) through computational modeling, identifying a compound which interacts with the

10      active site, thereby identifying a compound, or its analog, as a compound which is useful for modulating the activity of such a polypeptide. This process is sometimes referred to as *in silico* screening. Sophisticated software for testing the probability of test compounds to interact with the target protein, which can test tens of millions of computer generated compounds, is available

15      to those skilled in the art.

Potential therapeutic compounds identified using the methods of the invention are usually tested in animal model systems to confirm the putative efficacy. Thus, in a further aspect, the present invention relates to a method for identifying a therapeutic agent, comprising:

20      a) administering to an animal an agent found to have activity using an assay or screening method as disclosed herein, and

            b) detecting in said animal a change in iron metabolism due to said administering,

            thereby identifying an agent for the treatment a disease of iron

25      metabolism.

Those skilled in the art are aware that typical measurements of iron metabolism that may be modulated in animal models (i.e., as a result of treatment with a potential therapeutic agent) include transferrin saturation, hepcidin levels, radioactive iron uptake in the gut, liver iron content, whole

30      body iron content, anemia indices. Specialized mouse models for study include anemic mice, iron overload mice, hemochromatosis mice (hfe/hfe), Hp mice (hypotransferrinemic mouse), and others.

In a further aspect, the present invention relates to a method for treating a condition in an animal afflicted with a disease of iron metabolism comprising administering to said animal an effective amount of an agent first identified by an 5 assay method of the invention. Preferably, said animal is a human patient, such as a patient afflicted with a disease of iron metabolism.

The screening assays of the invention thus simplify the evaluation, identification and development of therapeutic agents for the treatment of diseases of iron metabolism.

10 The invention also includes antibodies and immuno-reactive substances which target, interact with or bind to hemojuvelin, HFE2A Polypeptide or epitopes thereof. Polypeptides encoded by the polynucleotides disclosed herein can be used as an antigen to raise antibodies, including monoclonal antibodies. Such antibodies will be useful for 15 a wide variety of purposes, including but not limited to, therapeutic agents, functional studies, drug screening assays, and/or diagnostic agents. Monitoring the influence of agents (e.g., small organic compounds) on the expression or biological activity of the HFE2A polypeptides identified according to the invention can be applied not only in basic drug screening, but 20 also in clinical trials. For example, the effectiveness of an agent determined by a screening assay as described herein to increase or decrease gene transcription, protein levels, or biological activity can be monitored in clinical trials of subjects exhibiting symptoms of diseases of iron metabolism due to inadequate gene transcription, protein levels, or biological activity (for 25 example, the individuals studied herein. Alternatively, the effectiveness of an agent determined by a screening assay to modulate transcription of HFE2A Gene, as well as structurally and functionally related genes, including genes with high homology thereto, and including protein levels, or biological activity can be monitored in clinical trials of subjects exhibiting decreased altered 30 gene transcription, protein levels, or biological activity. In such clinical trials, the transcription or activity of the genes or polypeptides disclosed herein and,

preferably, other genes that have been implicated in, for example, iron metabolism, can be used to ascertain the effectiveness of a particular drug.

In a preferred embodiment, the present invention provides a method for monitoring the effectiveness of treatment of a subject with an agent (e.g., an agonist, antagonist, peptidomimetic, protein, peptide, antibody, nucleic acid, small molecule, or other drug candidate identified by the screening assays described herein) including the steps of (i) determining that a patient requires treatment for an iron metabolism disease or disorder; (ii) administering an effective amount of an agent identified using one of the screening assays disclosed herein; (iii) ascertaining an improvement in iron metabolism following said administration and (vi) altering the administration of the agent to the subject accordingly. For example, increased administration of the agent may be desirable to decrease the expression or activity of gene or encoded polypeptide, i.e., to increase the effectiveness of the agent.

Where the patient is non-human, biopsy samples can be taken to show a decrease in gene transcription, such as by measuring levels of protein, mRNA, or genomic DNA post-administration samples and comparing the level of expression or activity of said protein, mRNA, or genomic DNA in the pre-administration sample with that of the corresponding post administration sample or samples, thereby showing the effects of drug administration on one or more of the genes disclosed herein and concomitant reduction in problems with iron metabolism.

Purified or semi-purified HFE2A protein, or fragments thereof, or proteins corresponding to HFE2A, and any biochemically modified versions thereof, are themselves therapeutic agents of the invention. Recombinant or non-recombinant forms of these proteins or fragments can be administered to persons in need thereof for the treatment of disorders, such as diseases of iron metabolism. Those skilled in the art are familiar with techniques for generating such agents, and for determining conditions of administration.

Specific compounds which will modulate the gene expression or gene transcript levels in a cell of HFE2A include antisense nucleic acids, ribozymes and other nucleic acid compositions which specifically hybridize with the

HFE2A gene (including exons or introns of such genes, promoters, 3'-tails, and the like). These specific compounds are compounds of the invention, and are useful for treating the diseases discussed previously. Design and manufacturing of such compounds are well known to those skilled in the art.

5        Specific compounds which modulate the activity of HFE2A include antibodies (polyclonal or monoclonal) and modified antibodies or fragments of antibodies which specifically bind to an epitope of said polypeptide. These specific compounds are compounds of the invention, and are useful for treating the diseases previously discussed. Design and manufacturing of such

10      compounds are well known to those skilled in the art. In particular, humanized antibodies tend to be preferred, such as those generated using techniques provided by Abgenix, Inc. (Freemont, CA), Medarex, Inc. (Princeton, NJ), Protein Design Labs, Inc. (Freemont, CA), Genentech (South San Francisco, CA), and others.

15      Specific compounds which modulate the activity of HFE2A in the body include gene therapy vectors comprising all or a part of the HFE2A gene sequence or mutant HFE2A sequence. As is well known to those skilled in the art, gene therapy allows the delivery of HFE2A in an organism to cells where it is taken up and expressed, thus changing the level or amount of HFE2A

20      Polypeptide protein in such cell. These vectors thereby modulate the activity of HFE2A in the body and are useful for the therapeutic indications disclosed herein.

Specific compounds which modulate the activity of HFE2A in the body include small organic molecules. Such compounds may be naturally occurring, or they may be synthetic. Collections and combinatorial libraries of such compounds are widely available from commercial sources. As known to those skilled in the art, a screening assay, such as the assays disclosed in the instant specification, can be easily adapted to identify therapeutic agents which have the desired HFE2A modulating ability. Agonists, antagonists, or mimetics found to be effective at reducing disorders of iron metabolism may be confirmed as useful in animal models (for example, mice, chimpanzees, etc.). In other embodiments, treatment with a compound of the invention may

be combined with other therapeutic agents to achieve a combined, possibly even synergistic, effect.

Candidate modulators may be purified (or substantially purified) molecules or may be one component of a mixture of compounds (e.g., an 5 extract or supernatant obtained from cells). In a mixed compound assay, gene expression is tested against progressively smaller subsets of the candidate compound pool (e.g., produced by standard purification techniques, such as HPLC or FPLC) until a single compound or minimal compound mixture is demonstrated to modulate gene or protein activity or expression in a manner 10 having therapeutic effects.

### **Lead Optimization and Analog Development and Selection**

In general, novel drugs having therapeutic properties are identified from libraries, possibly large libraries, of both natural product or synthetic (or 15 semi-synthetic) extracts or chemical libraries according to methods known in the art. Those skilled in the field of drug discovery and development will understand that the precise source of test extracts or compounds is not critical to the screening procedure(s) of the invention. Accordingly, virtually any 20 number of chemical extracts or compounds can be screened using the exemplary methods described herein. Examples of such extracts or compounds include, but are not limited to, plant-, fungal-, prokaryotic- or animal-based extracts, fermentation broths, and synthetic compounds, as well as modification of existing compounds. Numerous methods are also available 25 for generating random or directed synthesis (e.g., semi-synthesis or total synthesis) of any number of chemical compounds, including, but not limited to, saccharide-, lipid-, peptide-, and nucleic acid-based compounds. Synthetic compound libraries are commercially available from Brandon Associates (Merrimack, NH) and Aldrich Chemical (Milwaukee, WI). Alternatively, libraries 30 of natural compounds in the form of bacterial, fungal, plant, and animal extracts are commercially available from a number of sources, including Biotics (Sussex, UK), Xenova (Slough, UK), Harbor Branch Oceanographics Institute (Ft. Pierce, FL), and PharmaMar, U.S.A. (Cambridge, MA). In

addition, natural and synthetically produced libraries are produced, if desired, according to methods known in the art, e.g., by standard extraction and fractionation methods. Furthermore, if desired, any library or compound is readily modified using standard chemical, physical, or biochemical methods.

5 De-replication(e.g., taxonomic de-replication, biological de-replication, and chemical de-replication, or any combination thereof) or the elimination of replicates or repeats of materials already known for their therapeutic activities may be employed whenever possible.

When a crude extract is found to have therapeutic activities, further 10 fractionation of the positive lead extract is possible to isolate chemical constituent responsible for the observed effect. Thus, the goal of the extraction, fractionation, and purification process is the careful characterization and identification of a chemical entity within the crude extract having such therapeutic activities. The same assays described herein for the 15 detection of activities in mixtures of compounds can be used to purify the active component and to test derivatives thereof. Methods of fractionation and purification of such heterogeneous extracts are known in the art. If desired, compounds shown to be useful agents for the treatment of pathogenicity are chemically modified according to methods known in the art. Compounds 20 identified as being of therapeutic value are subsequently analyzed using any standard animal model of an iron metabolism disorder known in the art.

In general, these screening methods provide a ready means for 25 selecting either natural product extracts or synthetic compounds of interest from a large population (i.e. a chemical library, for example, one produced by combinatorial means) which are further evaluated and condensed to a few active core structures. Multiple analogs of such core structures may be developed and tested to identify those preferred analogs which have improved characteristics as therapeutic agents.

Improved analogs may also include compounds with improved stability, 30 biodistribution, pharmacokinetics or other desirable features for therapeutic agents which are not directly related to modulation of the therapeutic target. In a preferred embodiment, the improved analog of the invention is effectively

delivered, either by physiological means or assisted means, to cells of the body expressing the HFE2A Polypeptide protein. Analog compounds are systematically screened to evaluate whether they modulate the identified biological activity and those that effectively do so are then therapeutic agents, 5 or further analogs thereof, according to the invention.

Therapeutic Agents and Uses Thereof

Those skilled in the art are familiar with the necessary steps for pre-clinical and human clinical trials which are used to establish efficacy and 10 safety of the new chemical entities and compounds first identified by the invention for use in treating the diseases mentioned herein.

Compounds first identified as useful therapeutic agents using one or more of the assays of the invention may be administered with a pharmaceutically-acceptable diluent, carrier, or excipient, in unit dosage form. 15 Conventional pharmaceutical practice may be employed to provide suitable formulations or compositions to administer such compositions to patients. Although oral administration is preferred, any appropriate route of administration may be employed, for example, intravenous, parenteral, subcutaneous, intramuscular, intracranial, intraorbital, ophthalmic, 20 intraventricular, intracapsular, intraspinal, intrathecal, epidural, intracisternal, intraperitoneal, intranasal, or aerosol administration. Therapeutic formulations may be in the form of liquid solutions or suspension; for oral administration, formulations may be in the form of tablets or capsules; and for intranasal formulations, in the form of powders, nasal drops, or aerosols.

25 Methods well known in the art for making formulations are found in, for example, Remington: The Science and Practice of Pharmacy, (19th ed.) ed. A.R. Gennaro AR., 1995, Mack Publishing Company, Easton, PA. Formulations for parenteral administration may, for example, contain excipients, sterile water, or saline, polyalkylene glycols such as polyethylene 30 glycol, oils of vegetable origin, or hydrogenated naphthalenes. Biocompatible, biodegradable lactide polymer, lactide/glycolide copolymer, or polyoxyethylene-polyoxypropylene copolymers may be used to control the

release of the compounds. Other potentially useful parenteral delivery systems for agonists of the invention include ethylenevinyl acetate copolymer particles, osmotic pumps, implantable infusion systems, and liposomes. Formulations for inhalation may contain excipients, or example, lactose, or

5 may be aqueous solutions containing, for example, polyoxyethylene-9-lauryl ether, glycocholate and deoxycholate, or may be oily solutions for administration in the form of nasal drops, or as a gel.

Combination therapies are also contemplated by the inventors. An therapeutic agent identified by one of the screening methods disclosed herein

10 15 may be administered along with another agent intended to treat a coincident conditions, such as where therapeutic and antitumor agents are given together or contemporaneously.

The present invention also relates to a process that comprises a method for producing a product, such as by generating test data to facilitate

15 20 25 30 identification of such product, comprising identifying an agent according to one of the disclosed processes for identifying such an agent (i.e., the therapeutic agents identified according to the assay procedures disclosed herein) wherein said product is the data collected with respect to said agent as a result of said identification process, or assay, and wherein said data is sufficient to convey the chemical character and/or structure and/or properties of said agent. For example, the present invention specifically contemplates a situation whereby a user of an assay of the invention may use the assay to screen for compounds having the desired enzyme modulating activity and, having identified the compound, then conveys that information (i.e., information as to structure, dosage, etc) to another user who then utilizes the information to reproduce the agent and administer it for therapeutic or research purposes according to the invention. For example, the user of the assay (user 1) may screen a number of test compounds without knowing the structure or identity of the compounds (such as where a number of code numbers are used the first user is simply given samples labeled with said code numbers) and, after performing the screening process, using one or more assay processes of the present invention, then imparts to a second user

(user 2), verbally or in writing or some equivalent fashion, sufficient information to identify the compounds having a particular modulating activity (for example, the code number with the corresponding results). This transmission of information from user 1 to user 2 is specifically contemplated 5 by the present invention.

In accordance with the foregoing, the present invention relates to a method for producing test data with respect to the modulation of HFE2A gene expression by a compound, comprising:

- 10 (a) a genetic construct comprising a reporter gene operably linked to an HFE2A promoter under conditions supporting expression of said reporter gene;
- (b) determining a change in expression of said reporter gene as a result of said contacting, wherein said change shows modulation, and
- 15 (c) producing test data with respect to the gene modulating activity of said test compound based on a change in expression of the determined genes indicating gene modulating activity.

In another such embodiment, the present invention relates to a method for producing test data with respect to the modulation of an HFE2A polypeptide activity by a compound, comprising:

- 20 (a) contacting a test compound with an HFE2A polypeptide and under conditions promoting an activity of said HFE2A polypeptide;
- (b) determining a change in activity of said polypeptide as a result of said contacting, wherein said change shows modulation, and
- 25 (c) producing test data with respect to the HFE2A polypeptide modulating activity of said test compound based on a change in an HFE2A polypeptide activity indicating modulating activity.

#### Diagnostics and Pharmacogenomics

In a further embodiment, the invention relates to diagnostic and 30 pharmacogenomic compounds, kits and methods. This aspect relates to analysis HFE2A Gene (HFE2A, hemojuvelin gene) for the diagnosis, including prognosis of onset or severity of onset, of juvenile hemochromatosis, adult

onset hemochromatosis, a disorder of iron metabolism, or in the selection of a therapeutic agent for a patient (i.e. pharmacogenomics). It also relates to the use of HFE2A diagnosis to classify patients having or at risk of having a disease of iron metabolism.

5 For example, nucleic acid analysis can be used to identify the HFE2A mutations disclosed herein, thus confirming the diagnosis of juvenile hemochromatosis.

Using the nucleic acid sequences disclosed in this invention, both the wild-type (non-disease associated) sequences (SEQ ID No. 1 - 9) and the 10 disease associated (mutated) sequences (SEQ ID Nos. 14, 16, and 18), those skilled in the art are capable of developing numerous different types of nucleic acid diagnostic methods, compounds and kits. Techniques include DNA sequencing, hybridization probing, single stranded conformational analysis, PCR based techniques such as mismatch amplification, and myriad other well 15 known methods. All such analysis can be performed on a small sample of blood, saliva, urine or other tissue provided by the patient.

Alternatively, using the protein sequences disclosed in this invention (SEQ ID No. 10 - 12) protein based analyses such as antibody based assays (Elisa, Radioimmunoassay and the like) can be employed to identify the 20 expression, amount or presence or absence of a normal or mutant HFE2A protein (HFE2A Polypeptide), such as those mutant polypeptides that result from the mutations disclosed herein.

Gene transcription, both comparable and absolute, as well as biological activity, and mutational analysis can each serve as a diagnostic tool for a 25 disease of iron metabolism; thus determination of the amount of HFE2A mRNA can be used to diagnose the presence or absence of a mutation correlated with such a disease.

Based on the instant invention, those skilled in the art will also be able to develop other biochemical, chemical and diagnostic assays of HFE2A, 30 mutation which are suitable for use with animal tissue samples.

A valuable embodiment of the invention will be to use the diagnostic assays to classify patients having or at risk of having a disease of iron

metabolism. There are many risk factors for diseases of iron metabolism, such as enhanced serum ferritin levels, transferrin receptor saturation, or identification of a mutation in a gene for hemochromatosis (i.e. the Hfe gene). Not all of these risk factors lead to the development of a disease of iron metabolism. Using the teaching of the invention, it is now possible to take patients at risk of having a disease of iron metabolism based on a known risk factor and further assessing them for mutations in HFE2A, wherein a mutation in HFE2A (in one or both copies of the gene) indicates a statistically greater chance of developing the disease of iron metabolism. This discovery particularly aids in diagnosis and prognosis of the risk of adult onset hemochromatosis, which correlates only loosely with the known mutations in the Hfe gene.

What follows is an example of the diagnostic benefit of HFE2A in relation to adult onset hemochromatosis. Nucleic acid or protein analysis used to identify HFE2A mutations disclosed herein, could be used to predict onset or severity of adult hemochromatosis. Adult hemochromatosis displays a wide variability in clinical penetrance. In some human subjects homozygous for HFE mutations there is early onset of a severe phenotype, while in other subjects homozygous for HFE mutations, they remain clinically normal. Assessment of HFE2A gene may be informative for which patients will manifest adult disease and which ones will remain relatively symptom free.

A patient was found to be heterozygous for a mutation in the Hfe1 gene at H63D. This mutation is considered a mild mutation which does not always result in onset of hemochromatosis. A second diagnostic test was then performed on the HFE2A gene. It revealed the following homozygous mutation:

Mutation in HFE2a	Type	Sequence
c.569C>A,p.A190D	WT	gtccaaggagCttggcctcta (SEQ ID NO. 31)
	MT	gtccaaggagAttggcctcta (SEQ ID NO. 32)

The patient developed adult onset hemochromatosis. Thus, detection of mutations in HFE2A is useful in identifying and classifying patients at risk of

developing hemochromatosis, because of a known risk factor (such as Hfe1 mutation), and determining which patients will develop the disease.

This invention therefore discloses a method of classifying a patient at risk of developing a disease of iron metabolism, comprising

- 5        a) performing a first assessment for a disease of iron metabolism, and  
              b) performing a diagnostic assay on HFE2A,

wherein a finding of mutation in HFE2A classifies said patient as having a statistically higher risk of developing said disease.

Pharmacogenomics deals with clinically significant hereditary variations  
10      in the response to drugs due to altered drug disposition and abnormal action in affected persons (Eichelbaum, M., Clin. Exp. Pharmacol. Physiol., 23:983-985, 1996; Linder, M. W., Clin. Chem., 43:254-266, 1997). In general, two types of pharmacogenetic conditions can be differentiated. Genetic conditions transmitted as a single factor altering the way drugs act on the body (altered  
15      drug action) or genetic conditions transmitted as single factors altering the way the body acts on drugs (altered drug metabolism). Altered drug action may occur in a patient having a polymorphism (e.g., a single nucleotide polymorphism or SNP) in promoter, intronic, or exonic sequences of HFE2A Gene. Thus by determining the presence and prevalence of polymorphisms  
20      allow for prediction of a patient's response to a particular therapeutic agent.

This pharmacogenomic analysis can lead to the tailoring of drug treatments according to patient genotype, including prediction of side effects upon administration of therapeutic agents, particularly therapeutic agents for treating disorders disclosed in this specification. Pharmacogenomics allows  
25      for the selection of agents (e.g., drugs) for therapeutic or prophylactic treatment of an individual based on the genotype of the individual (e.g., the genotype of the individual is examined to determine the ability of the individual to respond to a particular agent).

Diagnostics employing a gene or protein corresponding to HFE2A Gene (HFE2A) can also be useful in selecting patients for clinical trials of a potential therapeutic agent. Patients can be stratified according to the DNA or protein sequence of HFE2A Gene and their response to drug treatment can 5 be evaluated. Such stratification can greatly reduce the number of patients required to establish efficacy for a potential therapeutic agent.

The invention thus comprises compounds, reagents and kits which are designed to identify the presence or absence of mutations in the HFE2A gene.

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### Example 1

#### Identification of the genetic mutation responsible for juvenile hemochromatosis 2A (HFE2A).

3. We have collected ten Greek families including 13 individuals 15 with JHH. Pedigrees of these families are shown in Figures 9a-9d. Of these families (JH3-12), five have been reported previously (JH3-7) (Papanikolaou, G. et al. Linkage to chromosome 1q in Greek families with juvenile hemochromatosis. *Blood Cells Mol. Dis.* 27, 744-749 (2001)). Only one family, 20 JH7, is known to be consanguineous. We confirmed that the disease is consistent with linkage to 1q21 (HFE2A; OMIM 602390) in the new families by using 25 genotype markers, including six new microsatellite markers identified from genomic sequence. While the Build 31 human genome sequence assembly contains gaps and duplications, we were able to estimate the size 25 of the linkage interval, and define the linkage boundaries and gene content based on existing sequence contigs. Homozygosity mapping in JH7 defined the limits of the candidate region in an ~1.7 Mb interval between markers CA3AL590452 (141595604-141595847 bp) and CA1AL596177 (143293543-143293826 bp). (The primer sequences for each marker are in Table 6).

Homozygosity in this region was also observed in affected individuals 30 from seven families without known consanguinity. We obtained six different Greek haplotypes by constructing haplotypes using an additional 12 markers. Affected individuals from families JH3, 5, 6, 7, 10, 11 and 12 shared alleles for

at least 6 of 7 markers in the linked interval. Affected individuals from JH4 and 8 displayed different homozygous haplotypes.

Table 6.

D No.	Forward Primer	Reverse Primer
CA3AL 590452	cacttgagcccaggaaatttg (SEQ ID NO: 55)	gactcactgcagccctgacc (SEQ ID NO: 56)
CA1AL 596177	gtgtgctacaagttgccgaat (SEQ ID NO: 57)	gcttgaaaactgggagttgga (SEQ ID NO: 58)
CA1AL 355505	gggaaaatggtcccataattcct (SEQ ID NO: 59)	cgcctgccAATATGTTCT (SEQ ID NO: 60)
D1S44	GGTACTTAGCCTCGAAA TGAGA (SEQ ID NO: 61)	GTGTCACACAACTGGTT G GT (SEQ ID NO: 62)

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#### Identification of Mutations in HFE2A

Mutations in HFE2A, (LOC148738) ENSG00000168509, transcript ENST00000306561, Ensembl v.12.31.1, November, 2002.

We first sequenced one of three coding exons (ENSE00001277351, 10 v.12.31.1) in this gene. Sequencing was initially limited to those probands that probably carried unique haplotypes, from families JH3 and 4. The first mutation identified was in JH4-203, a T to C transition in the 3' exon (c.842T>C, p.I281T). JH4-203 is homozygous for this SNP. Two siblings and one child, all unaffected, are heterozygous for this SNP. This SNP was not 15 present in any other JH probands or family members and not present in 74 European and 74 Greek control chromosomes.

The second genetic variation identified within this exon is a G to T transversion (c.959G>T, p.G320V). This SNP was homozygous in the JH3 proband. The JH3 affected is homozygous for the c.959T allele and one 20 unaffected sib is heterozygous for this SNP. This SNP was not present in 128 European and 37 Greek control chromosomes. After sequencing all family members of the 10 JH families, it was determined that this SNP is homozygous in the affected individuals from families JH5, JH6, JH7, JH10,

and heterozygous in the JH11 proband and both parents of the JH12 proband.

A third variation, a deletion at nucleotide 1079 (c.1079delC, p.C361fsX366) was identified in the homozygous state in the JH8. This results 5 in 5 unique amino acids and a premature stop. This SNP was also present in the JH11 proband, indicating that this individual is a compound heterozygote.

Additional information about the sequences disclosed in the SEQ ID listing in this specification:

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LOC148738 Exons

Exons 1, 3a, 3b and 4 may also be found at Gene ENSG00000168509 (Ensembl) and REFSEQ NM\_145277.1 (NCBI). Exon 2 may be inferred from an ensembl prediction based on the sequence AK098165.1.

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To simplify sequence searching, exon sequence coordinates are provided below based on the NCBI 31 assembly of the human genome. The SEQ ID NOs for these are:

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SEQ ID NO. 1 - Exon1 ENSE00001155188

Start:142000393, End:142000541 Chr: 1

SEQ ID NO. 2 - Exon2

Start: 142001790, End: 142001993 Chr:1

SEQ ID NO. 3 - Exon3a ENSE00001155182

Start: 142002394, End: 142002430 Chr:1

SEQ ID NO. 4 - Exon3b ENSE00001277320

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Start: 142002394, End: 142002953 Chr: 1

SEQ ID NO. 7 – Transcript 2 ENST00000317920

Exons 1, 3a, 4, translation\_start: 208

SEQ ID NO. 8— Transcript 3 Exons 1, 3b, 4 translation\_start: 392

SEQ ID NO. 9 – Transcript 4 Exons 1, 2, 3b, 4 translation\_start: 257

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LOC148738 Translated Proteins

5 Protein1 is the protein translation of Transcript 1 and Transcript 2 and is similar to the Ensembl protein ENSP00000320072 and the NCBI protein NP\_660320.1. Protein 2 is the protein translation of Transcript 2 and may be found in the protein translation of AK098165.1. Protein 3 is similar to the predicted Ensembl Protein ENSP00000304614. SEQ ID NOs are as follows:

SEQ ID NO. 10 - Protein1 ENSP00000320072  
Translated from Transcript 1 and Transcript 2  
SEQ ID NO. 11 – Protein 2 –  
10 Translated from Transcript 3  
SEQ ID NO. 12 – Protein 3 ENSP00000304614  
Translated from Transcript 4

15 HFE2A Promoter Sequences for Human, Mouse and Rat

For SEQ ID Nos. 19 – 21, the promoter sequence is deemed to begin 1500 bp 5' of the transcriptional start site.

Human Genomic DNA fragment including HFE2A promoter region and exons have SEQ ID NOs as follows:

20 SEQ ID NO. 22 - Human Genomic DNA fragment including HFE2A promoter region and exons  
SEQ ID NO. 23 – similar to gi|24308189|ref|NP\_064596.1| Human RGM  
25 SEQ ID No. 24 – Similar to ENSESTP00000023393 Human HFE2A paralog on chromosome 5, sequence starting from first methionine  
SEQ ID NO. 25 – Similar to ENSMUSESTP00000016634 Mouse HFE2A  
30 SEQ ID No. 26 – Similar to gi|21758120|dbj|BAC05248.1| Rat HFE2A annotated as from Homo sapiens but nucleotide sequence identified as from rat  
SEQ ID No. 27 – Similar to SINFRUP00000138308 Fugu HFE2A, N-terminus not defined

SEQ ID No. 28 – Similar to gi|22651834|gb|AAM95449.1| Chicken  
RGM

Those skilled in the art will be familiar with numerous variations of the  
5 compositions and methods disclosed above, all of which are encompassed by  
the claims further set out below.